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IMPROVING HEALTHCARE FACILITY LOCATIONS IN BAMYAN, AFGHANISTAN

By

Yong Kiong Teo

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Thesis Advisor:	Nedialko Dimitrov
Second Reader:	Javier Salmeron

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The facility location problem is one of the oldest and most researched operations research problems. In this thesis, we utilize facility location models to determine the optimal locations and types of medical facilities to address the healthcare needs of the people in Bamyan Province, Afghanistan. The staffing levels and materials of a local medical facility in Afghanistan are designed to cope with the healthcare needs of the people. In this thesis, the medical facilities are defined to be part of a network system. These facilities can be strategically located in order to provide essential healthcare services to the population. We investigate the location, operating cost, and accessibility of the existing and future healthcare facilities. We also look into the ethnicity problem that would affect the selection of operators for the medical facilities. Our model would lead to an increased understanding of the impact of healthcare facility locations and the selection of operators, thus developing a cost-effective system that would involve the shifting or upgrading of existing healthcare facilities.

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IMPROVING HEALTHCARE FACILITY LOCATIONS IN BAMYAN, AFGHANISTAN

Yong Kiong Teo
Major, Singapore Armed Forces
B.Eng (Hons), University of Queensland, Australia 2006

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Author: Yong Kiong Teo

Approved by: Nedialko Dimitrov
Thesis Advisor

Javier Salmeron
Second Reader

Robert F. Dell
Chair, Department of Operations Research

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ABSTRACT

The facility location problem is one of the oldest and most researched operations research problems. In this thesis, we utilize facility location models to determine the optimal locations and types of medical facilities to address the healthcare needs of the people in Bamyan Province, Afghanistan. The staffing levels and materials of a local medical facility in Afghanistan are designed to cope with the healthcare needs of the people. In this thesis, the medical facilities are defined to be part of a network system. These facilities can be strategically located in order to provide essential healthcare services to the population. We investigate the location, operating cost, and accessibility of the existing and future healthcare facilities. We also look into the ethnicity problem that would affect the selection of operators for the medical facilities. Our model would lead to an increased understanding of the impact of healthcare facility locations and the selection of operators, thus developing a cost-effective system that would involve the shifting or upgrading of existing healthcare facilities.

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LIST OF ACRONYMS AND ABBREVIATIONS

BHC	Basic Health Clinic
BPHS	Basic Package of Health Service
CHC	Comprehensive Health Clinics
CHW	Community Health Workers
CPU	Central Processing Unit
DH	District Hospital
DoPH	Department of Public Health
GB	Gigabyte
GHz	Gigahertz
HP	Health Post
km	Kilometers
MGRS	Military Grid Reference System
NGOs	Non-Governmental Organizations
RAM	Random Access Memory
TBA	Traditional Birth Attendant
USAID	United States Agency for International Development

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EXECUTIVE SUMMARY

In this thesis, we aim to determine the optimal location and type of medical facilities to address to the healthcare needs of the people in Bamyan Province, Afghanistan. We do this using a variant of the facility location problem, one of the oldest and most researched operations research problems.

To model the location of healthcare facilities in Bamyan, we create a network model of transportation. The nodes of the network are the villages in Bamyan and the edges are defined by the available roads. We then formulate a linear, mixed integer location model to select the villages in which to place healthcare facilities. The model takes into account limitations such as the operating budget, infrastructure budget, capacity of the healthcare facilities, distance traveled by patients and other operational constraints. A key contribution of this thesis is the modeling of Afghan ethnic groups when it comes to selecting healthcare operators and locations. The model takes ethnicity into account by modeling each ethnic group's acceptance to being served at a healthcare facility operated by a different ethnic group. The main objective of the optimization problem is to minimize the total distance patients travel to receive healthcare.

Our model leads to an increased understanding of healthcare facility locations and the selection of operators in Bamyan. The mathematical model can help decision makers to identify–given a fixed operating and infrastructure budget–the types, locations, and ethnic operators of healthcare facilities that minimize the total distance traveled by patients to receive healthcare.

Our results show that with a limited operating and infrastructure budget, the locations of healthcare facilities in Bamyan District may be improved. Possible improvements include:

- Downgrade larger facilities into smaller ones;
- Relocate facilities to new locations with a minimal infrastructure budget of 200,000 USD;
- If further infrastructure budget is available, build new, small healthcare facilities at specified new locations.

In analyzing the ethnicity of healthcare operators, our model shows that the population of the major ethnic group travel shorter distances to arrive to a healthcare facility as compared to the minor ethinc group. More healthcare facilities are operated by the major ethnic group, even though the acceptance of the major ethincity is high. Facilities operated by the major ethnic group may still serve members of the minor ethnic group population who are willing to go to the facility that is not operated by its own ethicity. Members of the minor ethnic group who are unwilling to be served by an operator of a different ethnicity would have to travel farther, to a location operated by the minor ethnic group. In our results, where the ethnicity groups have an acceptance level of 60 percent, the patient of the major ethnicity travels about 5.76 km to a healthcare facility, whereas the patient of minor ethnicity travels about 9.75 km.

We derive our results using recent data gathered by coalition forces and the Bamyan Department of Public Health. However, our data does have some limitations. Naturally, with improved data on the population, ethnicity and location of demand nodes the model would be more accurate. Furthermore, more realism can be incorporated into our model, which focused only on the demand of the population and capacity of the facilities. Specifically, our model does not account for the types of services provided by the healthcare facilities and that services in a certain type of facility may not be available in another. Incorporating service types would likely change the suggested facility types and locations produced by the model.

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I. INTRODUCTION

A. OVERVIEW

Basic healthcare does not reach the majority of the population in developing countries due to poor geographical accessibility. Numerous operations research studies have focused on facility location problems to help developing countries plan their healthcare system.

Facility location problems investigate the location, cost, accessibility and types of facilities and services. These studies analyze the relationship and impact between the facilities' locations and the people it serves. Solving the facility location problem helps decision makers make critical changes to the healthcare services and hence improving the quality of lives.

B. BACKGROUND AND MOTIVATION

1. Healthcare in Bamyan Province

Bamyan Province is located in one of the most mountainous, isolated and barren areas in the center of Afghanistan (see Figure 1). The province is composed of seven districts: Waras, Panjab, Yakawlang, Shibar, Saighan, Kahmard and Bamyan Center. Bamyan Province covers roughly 18,029 square kilometers, accounting for 2.76 percent of the country, with an elevation of about 2,500 meters above sea level. Bamyan is the cultural capital of the Hazara ethnic group, which is in the majority in this area. The province is also inhabited by smaller number of Tajiks, Pashtuns and Qezelbash.

Bamyan experiences extreme winter temperatures, with high snowfalls. It is considered one of the most impoverished provinces in the country, with very poor healthcare services. The Bamyan Department of Public Health (DoPH) was formed to govern the development of the province's healthcare system. Its priorities are to establish the core health services of the Basic Package of Health Service (BPHS) in Bamyan and to add other services that are not part of the BPHS (Bamyan Provincial Health Directorate, 2008).

The purpose of the BPHS is to provide a standardized package of basic services that forms the core of service delivery in all primary healthcare facilities, and to improve the quality of healthcare service in the underserved areas through the redistribution of healthcare services (Afghanistan Research and Evaulaution Unit, 2002).

Figure 1. Map of Afghanistan

The BPHS provides a comprehensive list of health services that are offered at four standard levels of health facilities within the proposed national health system: the health post (HP), basic health center (BHC), comprehensive health center (CHC) and the district hospital (DH).

Basic health services that are delivered by community health workers (CHWs) and traditional birth attendants (TBAs) out of their own homes function as a community HP. In addition to delivering the BPHS, CHWs are responsible for treating common illnesses and conditions in children and adults. TBAs provide care for normal deliveries, identify danger signs, and refer patients to health centers. A HP staffed by one female or male CHW and one TBA covers a service area population of 1,000 to 1,500 people, equivalent to 100 to 150 families.

The BHC is a small facility, offering the same services as an HP, but with more complex outpatient care. It is staffed by a nurse, a midwife or auxiliary midwife, and vaccinators, covering a patient population of 15,000 to 30,000.

The CHC covers a larger service area of 30,000 to 60,000 people, and offers a wider range of services than the basic health center. The facility has space for inpatient care, as well as a laboratory. The staffing of a comprehensive center is also larger than that of a basic center, including both male and female healthcare providers.

The DH, which serves up to four districts, handles all services in the BPHS, including the most complicated cases. The hospital is staffed with doctors, including female specialists in obstetrics and gynecology, and may be staffed with additional specialists including a surgeon, anesthetist, and pediatrician. Each district hospital covers a population of 100,000 to 300,000, servicing up to four districts, depending upon the geographic accessibility to the facility. Refer to Table 1 for the summary of healthcare services provided by the different types of healthcare facilities (Islamic Government of Afghanistan, Ministry of Health , 2003).

Table 1. Summary of healthcare services provided by different healthcare facilities

Type of Healthcare Facilities	**Services Provided**
Health Post (HP)	Limited curative care, including: diagnosis and treatment of malaria, diarrhea and acute respiratory infection; distribution of condoms and oral contraceptives; and micronutrient supplementation.
Basic Health Clinic (BHC)	Antenatal, delivery, and postpartum care; family planning; routine expanded program on immunization; growth monitoring; management of childhood diseases; and treatment of malaria and tuberculosis and distribution of essential drugs.
Comprehensive Health Clinic (CHC)	Deliveries and delivery complications; grave cases of childhood illness; treatment of complicated cases of malaria; and inpatient and outpatient physiotherapy for disability.
District Hospital (DH)	Same as CHCs, and wide range of essential drugs and laboratory services including X-ray, dental and anesthetic services.

2. Motivation

The healthcare system in Bamyan is mainly supported by non-governmental organizations (NGOs) and some Afghani healthcare providers. The main priorities of the DoPH are to identify essential healthcare facilities in the underserved areas and to redistribute the healthcare facilities to address the essential healthcare needs. The DoPH also aims to provide equitable healthcare access to the population in Bamyan.

There is very little coordinated effort among NGOs, private healthcare providers and the DoPH to determine the location of the healthcare facilities. The HP and BHC are built or co-located in the house or courtyard of village heads. Topological characteristics of the facility and demands of the village are seldom considered when determining the location of the healthcare facilities (Jia, 2005).

C. RESEARCH OBJECTIVES

Over the years, NGOs and healthcare providers have established numerous clinics and HPs. There is no proper system to ensure the establishment of these healthcare facilities can provide equitable access for the population. A study into the distribution of healthcare facilities can improve this situation. The objective of this research is to develop a methodology to help decision makers answer the following questions:

- What types and numbers of healthcare facilities are required?
- Can the current healthcare facilities be redistributed to provide equitable access? Can the healthcare facilities be relocated or expanded?
- Given that due to historic ethnic tensions in Afghanistan, some ethnic groups are unwilling to go to medical facilities run by differing ethnic groups, how can operation of the healthcare facilities be equitably distributed amongst the region's ethnic groups?

This thesis aims to improve the distribution of healthcare facility locations to provide equitable access for the population in Bamyan, Afghanistan. This thesis also aids in the continuity planning for healthcare facilities in Bamyan. With an understanding of the importance and impact of the healthcare facility locations, the DoPH can prioritize the types of healthcare facilities to be built at this critical location.

II. FACILITY LOCATION MODELS

A. FACILITY LOCATION MODELS

Facility location models have been studied since the 1960s (Hakimi, 1964, 1965). These have been used to locate airports (Saatcioglu, 1982), bus terminals (Campbell, 1990), warehouses (Perl, 1985), hospitals (Daskin, 1982), and even satellites (Drezner, 1988). Location models are application-specific, that is, uniquely built on their defined objectives and constraints.

B. BASIC FACILITY LOCATION MODELS

In this section, we present several basic facility location models that have been widely researched: set covering, maximal covering, p-median and fixed charge. In these models, the underlying network, demands, and facility locations are given. The general problem is to identify the location of new facilities in order to optimize specified objectives.

1. Set Covering Location Model

This model is usually used in a maximum-distance problem, an example of which is a new bus company siting its bus service facilities (i.e., bus terminal and bus stops) in a new town. The bus company wants to minimize the maximum distance traveled by any commuter to any bus service facility, so that they provide fair service to all. For example, those customers who stay within a kilometer of the bus terminal are expected to walk to the bus terminal, whereas bus stops are built for those who would need to walk more than one kilometer.

The first location covering problem was the set covering problem (Toregas, 1971). The objective of the model is to locate the minimum number of emergency services facilities required to serve all the demand. Therefore, in the bus terminal problem, each possible facility location (i.e., bus terminal or bus stops) covers a set of customers—those within a 1 km walking distance. The goal of the bus terminal problem is to find the minimum number of sites that cover all customers.

2. Maximal Covering Location Model

A set covering location model assumes that demand nodes are to be covered without any budget restriction. In most location models, “budget constraint” often refers to the amount of money available to build or run the facility. A budget constraint is used in the model to set a limit to the number of facilities that can be built. For example, in the bus company problem, the company may not be able to cover the whole town; the budget constraint would limit the number of bus service facilities that can be built.

A maximal covering location problem (Chruch, 1974) was formulated to address the planning situations that have an upper limit on the number of facilities to be sited. The objective of the problem is to locate a fixed number of facilities in such a manner that the maximum demand is covered by the facilities.

3. p-Median Model

The p-median model (Hakimi, 1964) finds the locations of *p* facilities to minimize the demand-weighted total distance between the demand nodes and the facilities that to which they are assigned.

4. Fixed Charge Location Model

The p-median model makes three assumptions that may not be appropriate for certain siting scenarios.

- Same cost for siting facility at each potential site.
- Facilities do not have capacities on the demand they can serve.
- A fixed number of facilities to open.

The fixed charge location model (Daskin, 1995) relaxes all three assumptions. The objective of the fixed charged location model is to minimize the total facility and transportation cost. It also determines the optimal number and location of facilities and the assignment of demands to those facilities.

C. MULTI-OBJECTIVES MODELS

Many facility location models have multiple objectives. The selection of objectives often involves several decisions from the varied stakeholders with different perspectives. The final decision may be made on political or pragmatic considerations that are not part of the considerations in the formal analysis. As a result, the decisions can very often be far from the optimal (Fisher, 1979).

Multi-objective models can be solved through two approaches: generating techniques and preference-based techniques (Cohon, 1978). Generating techniques identify the Pareto-optimal siting of the facilities from the preferences of the decision makers. Preference-based techniques use a ranking method to rank the objectives and then find the solution that optimizes the ranking. Ranking may be done through the use of simple weighting or complex analytical methods.

Multiple distance-related objectives have been developed in some studies to highlight the importance of distance. Schilling (1980) included several different maximum covering objectives for fire equipment locations. Church (1991) employed a maximum-distance objective and an average-distance objective. Multiple objectives could also include objectives related to cost, risk and the equity of risk.

D. STOCHASTIC LOCATION MODELS

Many of the facility location models are dynamic in nature. Demand, cost, travel time and distance may change with time, and these parameters may be random. This is evident in facilities that are designed to stay in a location for a long time. Facility location models where demand, cost, travel time, or distances are only known through a probability distribution are called stochastic location models. They have been used to solve location problems with parameter that would change over time. There have been several approaches to the stochastic location models.

One of the approaches is to use scenario planning. The scenarios would represent all possible values for parameters that may change over the planning timeframe. One of the applications of using scenario planning in solving stochastic location models was the application by Sheppard (1974), who minimized the expected cost of all scenarios.

Another approach develops chance-constrained models. Daskin (1982,1983) formulated a probabilistic extension of a maximal covering problem in which facilities are assumed to be busy with probability p. If the facilities are busy, they cannot serve the demand. The objective of the model is to maximize the number of demands being covered by an available facility.

E. HEALTHCARE FACILITY LOCATION PROBLEM IN BAMYAN

In this research, we adopt three objectives to locate healthcare facility locations: median, covering, and fixed-charge objectives. The objectives of our models are as follows:

- Median distance objective is to minimize the demand-weighted total distance, or transportation cost, between demand nodes and facilities.
- Basic covering objective is to minimize the number of facilities needed to cover all the customers.
- Fixed charge objective is to minimize infrastructure, operating costs and transportation costs.

Our models for optimizing healthcare facility locations in Bamyan, Afghanistan, are discussed in Chapter III.

III. MODEL FOR OPTIMIZING HEALTHCARE FACILITY LOCATIONS

A. BASIC HEALTHCARE FACILITY LOCATION MODEL

In this thesis, we adopt a basic healthcare facility location model (Daskin, 1995), which has an objective function that minimizes the sum of two functions: (1) the operating cost of the healthcare facility at location *j*, and (2) the cost of total distance traveled by patients.

The model has the following indices:

i, index for villages;

j, index for locations.

The model has the following parameters:

f_j = operating cost of the healthcare facility at location j $[\$]$;

h_i = demand at village i $[\text{persons}]$;

d_{ij} = distance from village i to healthcare facility at location j $[\text{km}]$;

α = cost per unit distance per unit demand $[\$/\text{person} \times \text{km}]$.

The decision variables are as follows:

$$X_j = \begin{cases} 1, & \text{if we locate a healthcare facility at location } j \\ 0, & \text{otherwise} \end{cases}$$

Y_{ij} = fraction of demand at village i that is served by healthcare facility at location j

The basic healthcare facility location model is as follows:

Minimize:

$$\sum_j f_j X_j + \alpha \sum_j \sum_i h_i d_{ij} Y_{ij} \qquad (1.1)$$

s.t.

$$\begin{cases} \sum_j Y_{ij} = 1 & ,\forall i \qquad (1.2) \\ Y_{ij} \le X_j & ,\forall i, j \qquad (1.3) \\ X_j \in \{0,1\} & ,\forall j \qquad (1.4) \\ Y_{ij} \ge 0 & ,\forall i, j \qquad (1.5) \end{cases}$$

The first part of objective function (1.1) is the total operating cost of the healthcare facility located at location *j*. The second part is the cost of total distance traveled by patients. It stipulates the cost of the total fraction of demand at village *i* served by some healthcare facilities multiplied by the distance traveled from *i* to *j*. Constraint (1.2) stipulates that the demands at village *i* is served by some healthcare facilities. Constraint (1.3) denotes that demands at village *i* cannot be assigned to a healthcare facility at location *j* unless at that facility is built. Constraints (1.4) and (1.5) are the integrality and non-negativity constraints, respectively.

B. REALISTIC ASPECTS OF OUR MODEL

The realities of Bamyan healthcare system require a more complex facility location model that more accurately captures several aspects of the problem. These include facility types, facility capacities, facility cost, patient ethnicity, and travel costs.

1. Facilities Types, Capacity, and Costs

The BPHS of the Afghan health system clearly specifies several different types of facilities: HPs, BHCs, CHCs, and DHs. It also lists the capacity, staff, equipment, diagnostic services, and medications required for each type of facility (Islamic Government of Afghanistan, Ministry of Health, 2003).

2. Travel Distance and Transportation Costs

The distance of concern in our model is the distance separating the patients from the villages and the healthcare facility. It is possible to model the road and trail network in Afghanistan with the purpose of computing the routes patients would use to access healthcare facilities. The location of healthcare facilities plays an important role in reducing the transportation cost, and thus it is important to identify the best possible path from the demand node to the facility. The cost of travel to the nearest facility is subject to the extreme weather conditions in Afghanistan. For example, rain or snow can close the mountainous trails and roads that many villages use for healthcare access, and leave only much lengthier paths on dirt roads available.

3. Patient Demands and Ethnicity

Bamyan was exposed to heavy fighting during the country's internal wars and harsh ruling under that Taliban. Many suffered during these conflicts. Many of these conflicts were due to ethnicity and differences in religion; therefore, community living in Bamyan is not common. The ethnicities in Bamyan district are mainly Hazarans (82 percent), Sadat (12 percent), Quizibach (one percent), Tajik (five percent), and very few Pashtoon families. People belonging to the same ethnicity prefer to deal with their own ethnicity, even to request medical help. Therefore, ethnicity becomes an important factor in deciding the operators of the healthcare facility.

C. IMPLEMENTING REAL-WORLD FEATURES INTO MODEL

1. Extended Healthcare Facilities Location Model

From the basic model in Section A, we can add additional constraints and variables to make the model more realistic. We may add facility capacities and infrastructure cost to the basic model by adding these parameters:

$e_j =$ capacity of the healthcare facility at location j [number of patients];

$g_j =$ infrastructure cost of healthcare facility at location j [\$] ;

B_{INFRA} = budget available for infrastructure upgrade or new facilities [\$];

B_{OPR} = budget available for operating the healthcare facilities [$].

The extended healthcare facilities location model is as follows:

Minimize:

$$\sum_j \sum_i h_i d_{ij} Y_{ij} \qquad (2.1)$$

s.t.

$$\begin{cases} \sum_j g_j X_j \le B_{INFRA} & (2.2) \\ \sum_j f_j X_j \le B_{OPR} & (2.3) \\ \sum_j Y_{ij} = 1 \quad ,\forall i & (2.4) \\ Y_{ij} \le X_j \quad ,\forall i, j & (2.5) \\ \sum_i h_i Y_{ij} \le e_j \quad ,\forall j & (2.6) \\ X_j \in \{0,1\} \quad ,\forall j & (2.7) \\ Y_{ij} \ge 0 \quad ,\forall i, j & (2.8) \end{cases}$$

The new objective function (2.1) is the total distance traveled by patients to the healthcare facility. It stipulates the total fraction of demand at village *i* served by healthcare facility at location *j* multiplied by the distance traveled from *i* to *j*.

Constraint (2.2) stipulates the total infrastructure cost of the healthcare facility located at location *j* should not exceed the infrastructure budget, B_{INFRA}.

Constraint (2.3) stipulates the total operating cost of the healthcare facility located at location *j* should not exceed the operating budget, B_{OPR}.

An additional constraint (2.6) is added to the model. It stipulates that demands at each village *i* that is served by facility at location *j* cannot exceed the capacity of facility at location *j*.

We further develop the model to incorporate three different types of healthcare facilities that can be built in Bamyan as follows. First, we drop the operating cost, f_j, capacity, e_j, and infrastructure cost, g_j, parameters and replace them with the following, where *k* is an index for facility type:

f_j^k = operating cost of healthcare facility type *k* at location *j* [$];

e_j^k = capacity of healthcare facility type *k* at location *j* [number of patients];

g_j^k = upgrading or building cost of healthcare facility type *k* at location *j* [$].

The original decision variable, X_j, is removed and the following decision variables of healthcare facilities are added to the model:

$$X_j^k = \begin{cases} 1, & \text{if we locate a facility of type } k \text{ at location } j \\ 0, & \text{otherwise} \end{cases}$$

With the change to the decision variables, cost and capacity parameters of the different types of healthcare facility, the following new demand variable is added:

Y_{ij}^k = fraction of demand at village *i* that is served by healthcare facility type *k* at location *j*.

The capacity healthcare facilities location model is as follows:

Minimize:

$$\sum_i \sum_j \sum_k h_i d_{ij} Y_{ij}^k \qquad (3.1)$$

s.t.

$$\begin{cases}
\sum_j \sum_k f_j^k X_j^k \le B_{INFRA} & (3.2) \\
\sum_j \sum_k g_j^k X_j^k \le B_{OPR} & (3.3) \\
\sum_j \sum_k Y_{ij}^k = 1 \quad ,\forall i & (3.4) \\
Y_{ij}^k \le X_j^k \quad ,\forall i, j, k & (3.5) \\
\sum_i h_i Y_{ij}^k \le e_j^k \quad ,\forall j, k & (3.6) \\
X_j^k \in \{0,1\} \quad ,\forall j \text{ ,k} & (3.7) \\
Y_{ij}^k \ge 0 \quad ,\forall i, j, k & (3.8)
\end{cases}$$

The objective function (3.1) is the total distance traveled by patients to the healthcare facility type *k* located at location *j*. It stipulates the total fraction of demand at village *i* served by healthcare facility type *k* multiplied by the distance traveled from *i* to *j*.

Constraint (3.2) stipulates the total infrastructure cost of the healthcare facility type *k* located at location *j* should not exceed the infrastructure budget, B_{INFRA}.

Constraint (3.3) stipulates the total operating cost of the healthcare facility type *k* located at location *j* should not exceed the operating budget, B_{OPR}.

Constraint (3.4) stipulates that the demands at village *i* are served by some healthcare facility, regardless of type.

Constraint (3.5) denotes that demands at village *i* cannot be assigned to a certain of healthcare facility at location *j* unless the healthcare facility is built at location *j*.

Constraint (3.6) stipulates that demands at all village i that are served by healthcare facility type k at location j cannot exceed the designed capacity of healthcare facility type k at location j.

Constraints (3.7) and (3.8) are the integrality and non-negativity constraints.

2. Ethnicity Healthcare Facilities Location Model

Depending on the ethnicity data of the population, we can have a coarse percentage for the major ethnicity group in the province.

An ethnicity data set indexed by t is also added into the model:

$t \in \{A,\ B\}$;

We also introduce parameters:

h_i^t = demand at village i of ethnicity t [number of patients].

We call the coarse fraction for the major ethnicity group an ethnicity factor. By using an ethnicity factor, we can obtain coarse estimates of the demands of each ethnicity type in each village.

G = ethnicity factor, which refers to the fraction of the major ethnicity group that is in the population. [fraction]

The original demand in village h_i is now divided into two parts, with h_i^A representing the demand of the major ethnicity and h_i^B for the rest of the other ethnicities.

The coarse estimates can now be defined as follows:

$h_i^A = h_i G$ = demand at village i of the major ethnicity [number of patients];

$h_i^B = h_i(1-G)$ = demand at village i of other ethnicities [number of patients].

Because of historic ethnic tensions, some ethnicity groups in Afghanistan are less likely to visit healthcare facilities that are run by different ethnic groups. The acceptance level toward other ethnicity groups often depends on the particular ethnic group or region

of the country. For example, the major ethnicity Hazarans are generally more willing to accept another person of other ethnicities. Hazarans are also more willing to seek medical help from a non-Hazaran healthcare facility. An acceptance factor is added to the model to represent the acceptance level of the population going to a healthcare facility that is operated by another ethnicity.

s_i^t = acceptance level of demand of ethnicity *t* from village *i going* to a healthcare facility that is not operated by ethnicity *t*. [percentage]

In our model, we assume all the demands in the villages have the same ethnicity breakdown and acceptance level.

As the healthcare facilities in Bamyan are managed by different NGOs, it is important that the healthcare facilities are operated by an ethnicity group that the patients would visit. Therefore, certain variables and parameters are modified to model the ethnicity factor.

The parameters' modifications are as follows:

$f_j^{k,t'}$ = operating cost of the healthcare facility type *k* at location *j* by operated ethnicity *t'* [$];

$e_j^{k,t'}$ = capacity of the healthcare facility type *k* at location *j* by operated ethnicity *t'* [number of patients];

$g_j^{k,t'}$ = infrastructure cost of the healthcare facility type *k* at location *j* by operated ethnicity *t'* [$].

The variables modifications are as follows:

$$X_j^{k,t'} = \begin{cases} 1, & \text{if we locate facility type } k \text{ operated by ethnicity } t' \text{ at location } j \\ 0, & \text{otherwise} \end{cases}$$

$Y_{ij}^{k,t,t'}$ = fraction of demand at village i of ethnicity t that is served by healthcare facility type k operated by ethnicity t' at location j.

The ethnicity healthcare facilities' locations model is as follows:

Minimize:

$$\sum_{i}\sum_{j}\sum_{k}\sum_{t}\sum_{t'} h_i^t d_{ij} Y_{ij}^{k,t,t'} \tag{4.1}$$

s.t.

$$\begin{cases}
\sum_{j}\sum_{k}\sum_{t'} g_j^{k,t'} X_j^{k,t'} \leq B_{INFRA} & (4.2)\\
\sum_{j}\sum_{k}\sum_{t'} f_j^{k,t'} X_j^{k,t'} \leq B_{OPR} & (4.3)\\
\sum_{j}\sum_{k}\sum_{t'} Y_{ij}^{k,t,t'} = 1 \quad ,\forall i,t & (4.4)\\
Y_{ij}^{k,t,t'} \leq X_j^{k,t'} \quad ,\forall i,j,k,t,t' & (4.5)\\
\sum_{i}\sum_{t} h_i^t Y_{ij}^{k,t,t'} \leq e_j^{k,t'} \quad ,\forall j,k,t' & (4.6)\\
\sum_{j}\sum_{k}\sum_{t'|t'\neq t} Y_{ij}^{k,t,t'} \leq s_i^t \quad ,\forall i,t & (4.7)\\
\sum_{j}\sum_{k=DH}\sum_{t'} X_j^{k,t'} = 1 & (4.8)\\
\sum_{k}\sum_{t'} X_j^{k,t'} \leq 1 \quad ,\forall j & (4.9)\\
X_j^{k,t'} \in \{0,1\} \quad ,\forall j,k,t' & (4.10)\\
Y_{ij}^{k,t,t'} \geq 0 \quad ,\forall i,j,k,t,t' & (4.11)
\end{cases}$$

The objective function (4.1) is the total distance traveled by patients of ethnicity *t* to the healthcare facility type *k* operated by ethnicity *t'* located at location *j*. It stipulates the total fraction of demand of ethnicity *t* at village *i* served by healthcare facility type *k* operated by ethnicity *t'* multiplied by the distance traveled from *i* to *j*.

Constraint (4.2) stipulates the total infrastructure cost of the healthcare facility type *k* operated by ethnicity *t'* located at location *j* should not exceed the infrastructure budget.

Constraint (4.3) stipulates the total operating cost of the healthcare facility type *k* operated by ethnicity *t'* located at location *j* should not exceed the operating budget.

Constraint (4.4) stipulates that the demands of ethnicity *t* at village *i* are served by the healthcare facilities.

Constraint (4.5) denotes that the demands of ethnicity *t* at village *i* cannot be assigned to a healthcare facility type *k* at location *j* unless the specific type of facility is built at location *j*.

Constrains (4.6) stipulates that demands of ethnicity *t* from all village *i* that is served by the healthcare facility type *k* operated by ethnicity *t'* at location *j* cannot exceed the capacity of facility type *k* operated by ethnicity *t'* at location *j*.

Constraint (4.7) stipulates that total demands of ethnicity *t* from village *i* that are served by the healthcare facility type *k* operated by the other ethnicity *t'* at location *j* cannot exceed the acceptance level factor, *s* of ethnicity *t*.

Constraint (4.8) stipulates that one DH must be present.

Constraint (4.9) stipulates that one healthcare facility is allowed at each location *j*.

Constraints (4.10) and (4.11) are the integrality and non-negativity constraints.

IV. TEST CASE DESCRIPTION AND ASSUMPTIONS

A. COMMON DATA AND ASSUMPTIONS

Accurate data is critical for development and testing of healthcare facility location models. Unfortunately, specific data and detailed information on our Afghanistan scenario are not readily available. Data on healthcare locations, road networks, and healthcare demands are extremely difficult to obtain. This information would be essential to enable us to perform a credible, relevant analysis.

Despite the limited sources of information, we have obtained useful data from the Bamyan Department of Public Health (DoPH) in Bamyan.

1. Capacity, Cost, and Location of Healthcare Facilities

We assume a BHC and CHC will provides a range of healthcare services for about 15,000-30,000 and 30,000-60,000 patients, respectively. A DH provides coverage for 60,000-100,000 patients, respectively (Islamic Government of Afghanistan, Ministry of Health, 2003).

A BHC must be staffed by a doctor, a male nurse, a midwife, female nurse and vaccinators, while a CHC is staffed by two doctors, two nurses, two midwives, technicians and vaccinators. A DH is staffed with doctors, including female specialists in obstetrics and gynecology, and may be staffed with additional specialists including a surgeon, anesthetist, and pediatrician.

The operating cost of a healthcare facility includes the cost for employment, drugs, and general amenities such as petrol, water and food for warded patients. In general, the cost of drugs and amenities added up to about 40 to 50 percent of the annual employment cost. Therefore, a BHC, CHC and DH would require a total annual operating cost of $54,000, $100,800 and $328,500, respectively.

The operating cost of the healthcare facilities are as shown in Table 2.

Table 2. Annual operating cost of healthcare facilities in Bamyan District

Type of health workers and professionals	Monthly operating cost ($/worker)	Number of health workers in the health facility		
		BHC	CHC	DH
Outreach workers				
Community health supervisor	300	1	1	1
Vaccinator	350	2	2	2
Health providers				
Nurse (male)	350	1	1	5
Nurse (female)	350		1	5
Psychosocial counselor (nurse)	400		1	
Community midwife	400	1	2	
Midwife	450			4
Physician MD general (male)	750		1	2
Physician MD general (female)	750	1	1	2
Surgeon male	800			1
Anesthetist	750			1
Pediatrician	750			1
Dentist	800			1
Pharmacist	500			1
Physiotherapist	800			2
Paramedics, ancillary services staff				
Laboratory technician	450		1	2
Pharmacy technician	450		1	
X-ray technician	350			1
Dental technician	350			1
Support staff				
Administrator	350			1
Cleaners, guards	250	2		6
Driver	300		1	1
Annual employment cost	-	36,000	67,200	219,000
Drugs and miscellaneous cost	-	18,000	33,600	109,500
Total annual operating cost	-	54,000	100,800	328,500

The healthcare facilities listing from the DoPH gives specific data on existing healthcare facilities in the Bamyan Province (see Table 3).

Table 3. Specific locations of healthcare facilities in Bamyan District. (From Islamic Government of Afghanistan, DoPH, Bamyan, 2003)

No.	District	Military Grid Reference System (MGRS) coordinates	Longitude	Latitude	Name
1	Bamyan	42S UD 7738266536	67.65739	34.93390	Bamyan BHC 1
2	Bamyan	42S VD 1091436326	68.02769	34.66502	Bamyan BHC 2
3	Bamyan	42S VD 0874773500	68	35	Bamyan BHC 3
4	Bamyan	42S VD 0314553328	67.94096	34.81761	Bamyan BHC 4
5	Bamyan	42S UD 8937345452	67.79144	34.74520	Bamyan CHC 1
6	Bamyan	42S UD 7074452830	67.58683	34.80952	Bamyan CHC 2
7	Bamyan	42S UD 9254753909	67.82502	34.92178	Bamyan PH

2. Infrastructure Cost of Healthcare Facility

Based on our work and experiences in Bamyan's health sector (Tan, 2009), we have gathered construction costs for upgrading or the building of a different facility in Afghanistan (see Table 4). Two types of infrastructure costs are modeled:

- Building Cost: The cost of building a new infrastructure at a new location (see Figure 2).
- Upgrading Cost: The cost of upgrading an existing facility to the next level of facility (see Table 5).

Table 4. Infrastructure cost for healthcare facility. (From Teo, 2008)

Type of infrastructure cost	Construction work	Cost (US$)
Building cost	BHC	185,000
	CHC	340,000
	DH	1,600,00
Upgrading cost	Upgrading of BHC to CHC	230,000
	Upgrading of BHC to DH	1,000,000
	Upgrading of CHC to DH	600,000

Table 5. Estimated breakdown for upgrading a BHC to a CHC (From Teo, 2008)

No.	Job description	Estimated costing (US$)	Estimated time (wks)	Remarks
1	Site survey	$1,000.00	0.5	
2	Leveling of extension area	$5,000.00	2	
3	Demolish existing toilet	$3,500.00	1	Concurrent activity
4	Demolish squatters	$2,000.00	1	Concurrent activity
5	Extension of bridge to 2-way	$4,000.00	3	Concurrent activity
6	Renovation of current BHC	$20,000.00	2	Electrical, plumbing, hacking of wall for extension plan, etc
7	Construction of security wall	$35,000.00	5	Concurrent activity
8	Construction of guard shack	$4,000.00	2	Concurrent activity
9	Construction of generator shed	$3,000.00	2	Concurrent activity
10	Construction of toilet and septic tank	$12,000.00	4	Concurrent activity
11	Construction of well	$15,000.00	2	Concurrent activity
12	Construction of water storage	$4,000.00	2	Concurrent activity
13	Construction of extension building	$100,000.00	10	Concurrent activity
14	Wiring of electrical components	$5,000.00	3	Current and extension building
15	Plumbing works	$5,000.00	4	
16	Furnishing	$10,000.00	2	
17	Landscaping	$5,000.00	2	
Total		$233,500.00	4.5 months	

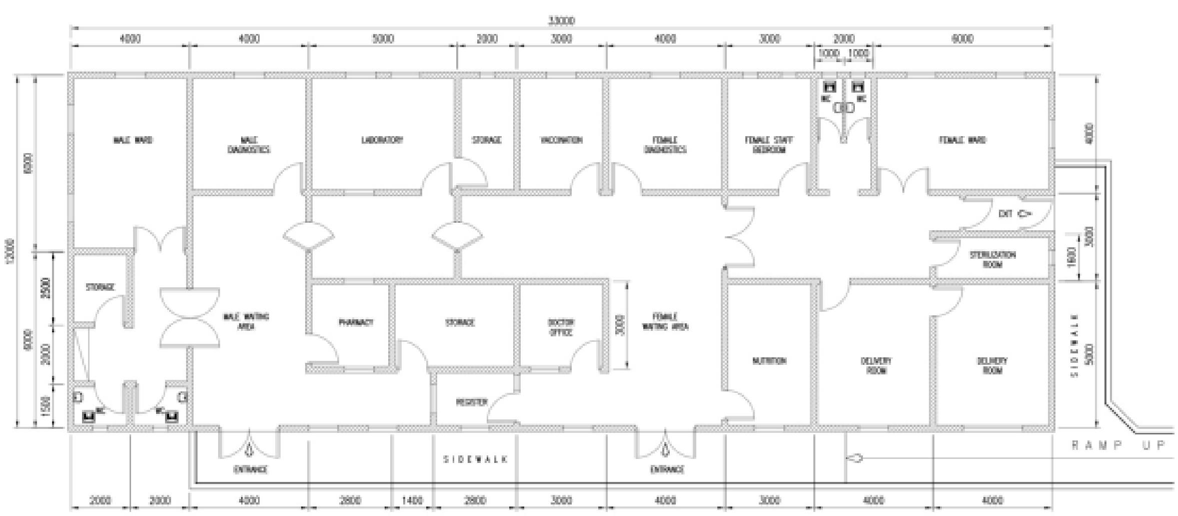

Figure 2. United States Agency for International Development (USAID) design of a typical BPHS CHC (From Teo, 2008)

3. Population and Location of Demand

We have not been able to obtain the specific location and population numbers for each small settlement in Bamyan. Using the information from the total population for each district, estimation is used to generate the health demand for each settlement. We model the major settlements in Bamyan District, and estimate their population by assuming that the district population is evenly distributed among settlements. Major towns appear as multiple clustered settlements, giving a larger concentration of population in those areas (see Figure 3). We model a total of 49 settlements (see Figure 4 and 5) in Bamyan District, with each settlement having a population of about 1,500 (see Table 6).

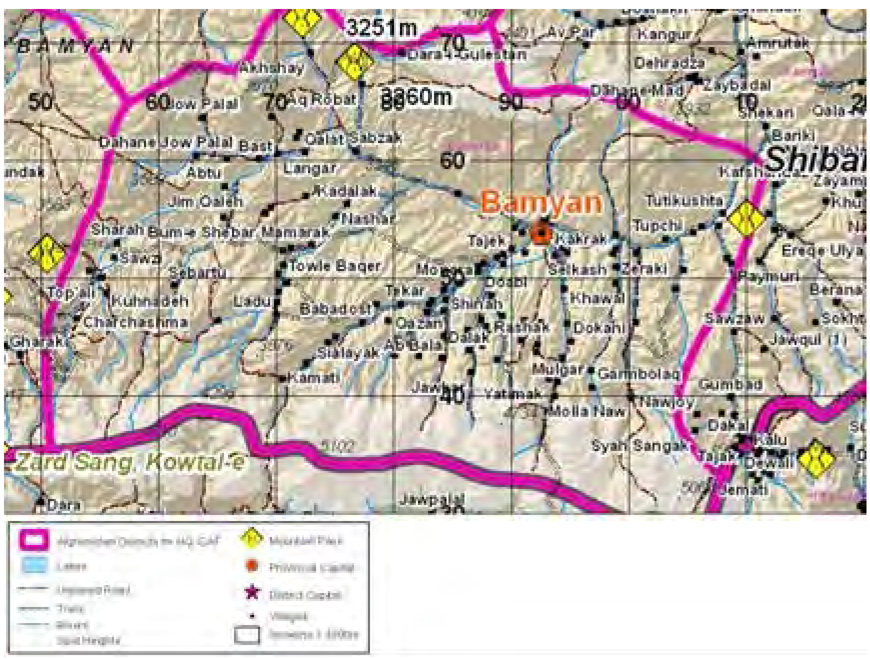

Figure 3. Geographic location of the settlements in Bamyan District (From Teo, 2008)

Table 6. Population of Bamyan Province by district. (From Teo, 2008)

District	Number of Males	Number of Females	Total Population
Bamyan	34,135	35,893	70,028
Shibar	11,878	11,055	22,933
Saighan	11,779	11,436	23,215
Kahmard	15,839	15,203	31,042
Yakawlang	33,195	32,963	66,158
Panjab	24,118	24,279	48,397
Waras	41,182	40,937	82,119
Total	172,126	171,766	343,892

4. Distance and Transportation Cost

The distance of concern in our model is the distance separating the patients from the village to the facility. The location of healthcare facilities plays an important role in reducing the transportation cost; thus, it is important to identify the best possible path from the demand node to the facility. Transportation costs would vary depending on the road condition between the demand node and facilities.

The Floyd–Warshall algorithm reference is used to determine the distance (d_{ij}) from the demand node to all the possible healthcare locations. The algorithm is not part of the model. A separate computation determines the shortest paths from each demand node to the possible healthcare facilities to generate the d_{ij} values for our model (Ahuja, et al., 1993).

The availability of the healthcare facilities is subjected to changing road conditions due to extreme weather conditions in Afghanistan. Certain roads in the road network are non-passable by vehicle during winter. We double the distance of the stretch of road to model the increased difficulty of traversing the road.

Transportation costs vary in terms of transportation used to travel to the nearest healthcare facility. Traveling on a bus for a distance of about 10 kilometers to arrive to a clinic costs a patient about USD $1. Many patients prefer to walk or ride on a donkey to get to the destination. On average, the locals will not walk more than two hours to get to a healthcare facility. We model the transportation cost using a transportation cost factor α, which is USD $0.1 per kilometer traveled.

B. TEST CASES

1. Baseline Scenario

For our area of interest in Bamyan District are assumed as follows:

Operating costs of the healthcare facility at location *j* [$]:

$f_j^{BHC} = 54,000$, $f_j^{CHC} = 100,800$, $f_j^{DH} = 328,500$, $\forall j$.

Capacity of healthcare facilities to be built at location *j* [number of patients]:

$e_j^{BHC} = 15,000$, $e_j^{CHC} = 30,000$, $e_j^{DH} = 60,000$, $\forall j$.

Infrastructure cost of the healthcare facility at location *j* [$]:

g_j^k depends on the type of work required for healthcare facility type *k* at location *j*. The cost ranges from $185,000 to $1,600,000 for building new facilities, and ranges from $230,000 to $1,000,000 for upgrading works.

Demand at village *i* [persons]:

h_i =1500, $\forall i$.

Distance from village *i* to healthcare facility at location *j* [km]:

d_{ij} (see Appendix A for details).

Cost per unit distance per unit demand [$/person $\times$km]:

α = 0.1.

Ethnicity factor [fraction]:

G = 0.8.

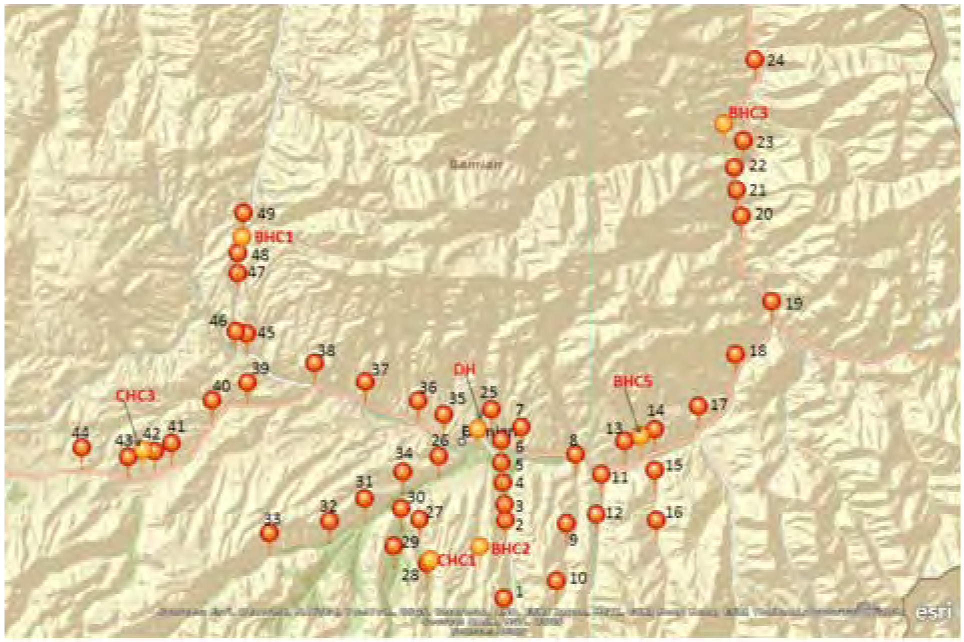

Figure 4. Bamyan District model plotted on ArcGIS Geographic Information System. (From Hiller, 2011)

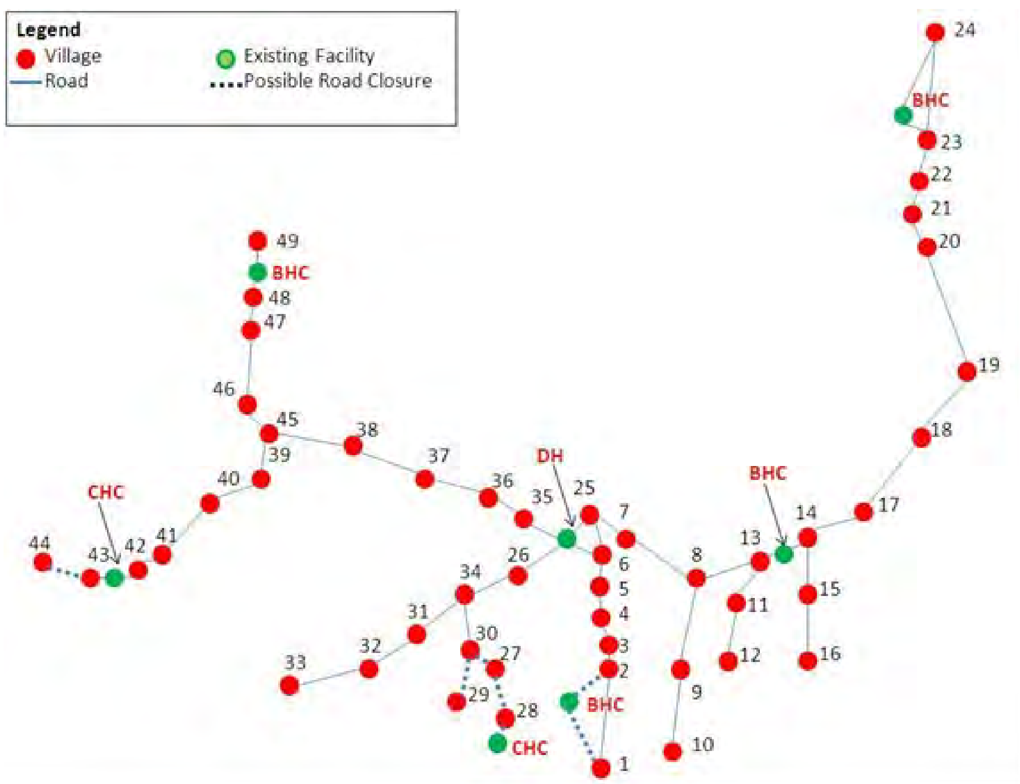

Figure 5. Road network of the model with possible road closure during winter.

2. Test Case 1

In the initial setup, topological locations of the healthcare facilities and total distance traveled by patients to facilities are not taken into consideration. In order to provide equitable access to healthcare facilities, the total traveled distance taken by patients has to be reduced. Therefore, in this test case, we want to determine the total operating cost and total traveled distance in the existing setup. Results from the test case will form the base value for comparison with the subsequent test cases.

3. Test Case 2

In this test case, we would like to find the optimal relocation of the existing healthcare facilities, given the infrastructure funding from donors.

The rest of the constraint remains unchanged as per the extended healthcare facilities location model. (See Chapter III, Section C.1.)

The number and type of healthcare facilities remain unchanged in this test case. We add two other constraints to model the number and type of healthcare facilities in the original setup.

$$\sum_j X_j^{BHC} = 4 \qquad (4.12)$$

$$\sum_j X_j^{CHC} = 2 \qquad (4.13)$$

Constraint (4.12) and (4.13) stipulates the total number of healthcare facility type BHC and CHC must be four and two, respectively.

4. Test Case 3

In this test case, we use our capacity healthcare facilities location model (see Chapter III, Section C.1) to determine the numbers and type of healthcare facility locations based on the infrastructure support from the donors. The operating cost of the healthcare facilities is kept at the base value.

5. Test Case 4

In this test case, we want to explore how operating costs and infrastructure costs affect the total traveled distance, and the number and type of healthcare facility locations. Results from this test case would serve as a critical guide for the DoPH to determine the number and types of healthcare facilities to operate if NGOs reduce its funding for operating the facilities. The results would also help the DoPH to determine the locations to build new facilities or which existing facilities to be upgraded based on available infrastructure funding from donors.

6. Test Case 5

In this test case, we strive to determine how the acceptance level of another ethnicity group affects the number and type of healthcare facilities operated by the different ethnicity groups. Using the ethnicity healthcare facility locations, we would be able to observe the change in ethnicity groups operating the healthcare facilities with respect to the change in acceptance level of another ethnicity group.

V. RESULTS

This chapter presents the results to our test cases described in Chapter IV. All the computations are executed on an Intel ® AtomTM CPU, 1.6 GHz computer with 2 Gb of RAM running under Microsoft Windows XP operating system.

The optimization models are coded in General Algebraic Modeling System (Brooke et al., 1998) and solved by CPLEX (ILOG, 2004).

In the next sections, our analysis is focused on the healthcare facilities' location based on the distance traveled, infrastructure support, operating budget, and ethnicity.

A. TEST CASE 1

Table 7. Results from Test Case 1

Location	**Existing clinics**	**Operating cost ($)**	**Designed capacity (persons)**	**Expected demand at location *j* based on shortest distance to facility**
A	BHC	54,000	15,000	9,000
B	BHC	54,000	15,000	4,500
C	BHC	54,000	15,000	7,500
D	BHC	54,000	15,000	13,500
E	CHC	100,800	30,000	6,000
F	CHC	100,800	30,000	9,000
G	DH	328,500	60,000	24,000
Total Operating Cost ($)				746,100
Total Traveled Distance (km)				385,200

In the results of Test Case 1, it is observed that the total distance traveled by the patients is 385,200 km, and the total operating cost of the healthcare facilities is $746,100. We set these values as our base-case scenario values for subsequent comparison.

B. TEST CASE 2

In Test Case 2, we sought to determine how much the traveled distance can be reduced by relocating the current healthcare facility locations (i.e., four BHCs, two CHCs and one DH) among the villages and current locations. The relocation requires additional infrastructure costs if there is a need for upgrading or building of new facilities at a new location. Therefore, the amount of infrastructure budget from donors affects the outcome (see Table 8 and Figure 6).

Table 8. Detailed results of Test Case 2.

Results from Test Case						
Infra-structure budget ($)	**Total traveled distance (km)**	**Infra-structure cost ($)**	**Healthcare facilities' location**			**Remarks**
			BHC	**CHC**	**DH**	
0	385,200	0	A B C D	E F	G	Current Plan
<100,000	385,200	0	A B C D	E F	G	No changes
<200,000	361,800	185,000	9 A C D	E F	G	Remove B and replace by 9
<300,000	361,800	185,000	9 A C D	E F	G	Remove B and replace by 9
<400,000	346,500	370,000	9 22 A D	E F	G	Remove B & C. Replace by 9 & 22
<500,000	346,500	370,000	9 21 A D	E F	G	Remove B & C. Replace by 9 & 21
<600,000	334,350	555,000	9 22 46 D	E F	G	Remove A, B & C. Replace by 9, 22 & 46
<700,000	334,350	555,000	9 21 46 D	E F	G	Remove A, B & C. Replace by 9, 21 & 46
<800,000	326,700	710,000	9 34 A D	21 F	G	Remove B, C & E. Replace by 9, 21 & 34
<900,000	314,550	895,000	9 22 34 D	46 F	G	Remove A, B, C & E. Replace by 9, 22, 34 & 46
<1,000,000	314,550	895,000	9 22 46 D	34 F	G	Remove A, B, C & E. Replace by 9, 22, 34 & 46

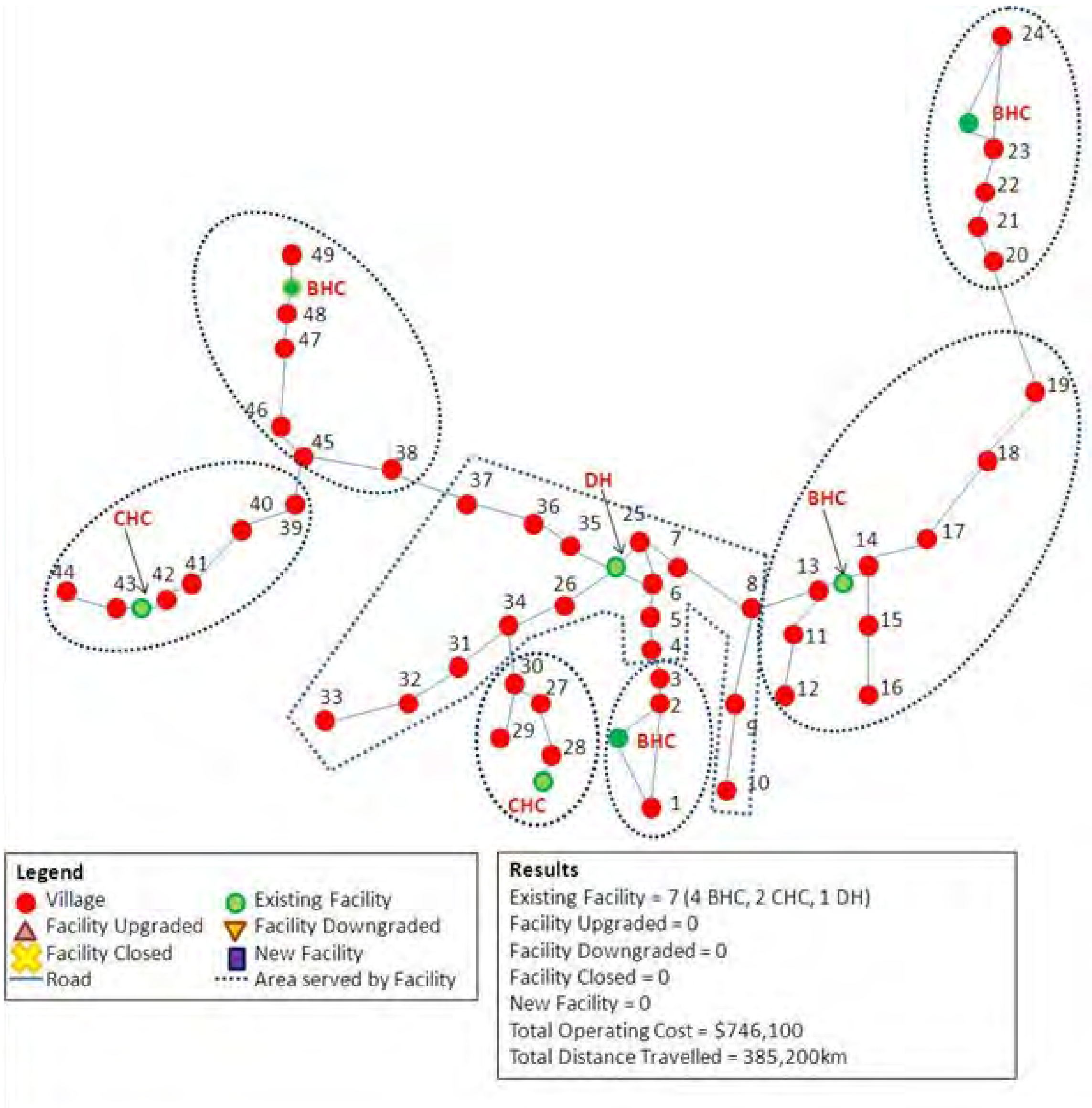

Figure 6. Scenario in Test Case 2 with limited operating cost (<$746,100), fixed number and type of facilities (4 BHCs, 2 CHCs and 1 DH) and no infrastructure support.

The increase in infrastructure budget allows the DoPH to reshuffle its current setup into new locations to reduce the total distance traveled by the patients. But the infrastructure cost of these new facilities is high, and may not be supported by donors. It is observed that the numbers and types of healthcare facilities in the current plan may not be the best scenario for Bamyan District. With an additional infrastructure cost of one

million dollars, the total distance is reduced by less than 19 percent. This help the patients to save about $7,000 in traveling cost each year, and it would take about 142 years to recover the investment

C. TEST CASE 3

In Test Case 3, we investigate the numbers and types of healthcare facilities that should be in place, based on the infrastructure budget from the donors. The total operating budget is kept to the base value, as this is the maximum available operating fund that the NGOs have to operate the healthcare facilities in Bamyan District.

Table 9. Detailed results of Test Case 3.

Constraints		**Results from Test Case**						
Infra-structure budget ($)	**Total operating budget ($)**	**Total traveled distance (km)**	**Total operating cost ($)**	**Infra-structure cost ($)**	**Healthcare facilities' location**			**Remarks**
					BHC	CHC	DH	
0	<746,100	385,200	746,100	0	A B C D	E F	G	Current Plan
0	<746,100	385,200	699,300	0	A B C D F	E	G	- Operate 1 existing CHC as BHC (F)
<100,000	<746,100	385,200	699,300	0				
<200,000	<746,100	342,900	706,500	185,000	9 A B C D E F	-	G	- Operate 2 existing CHCs as BHCs (E & F) -1 new BHC (9)
<300,000	<746,100	342,900	706,500	185,000				
<400,000	<746,100	321,000	706,500	370,000	9 38 A C, D E F	-	G	-Close 1 existing BHC (B) -Operate 2 existing CHC as BHC (E & F) -2 new BHCs (9,38)
<500,000	<746,100	321,000	706,500	370,000				
<600,000	<746,100	301,200	706,500	555,000	9 34 38 A C D F	-	G	-Close 1 existing BHC & CHC (B & E) -Operate 1 existing CHC as BHC (F) -3 new BHCs (9,34,38)
<700,000	<746,100	301,200	706,500	555,000				

Constraints		Results from Test Case						
Infra-structure budget ($)	**Total operating budget ($)**	**Total traveled distance (km)**	**Total operating cost ($)**	**Infra-structure cost ($)**	**Healthcare facilities' location** BHC	CHC	DH	**Remarks**
<800,000	<746,100	285,900	706,500	740,000	9 22 30 38 A D F	-	G	-Close 1 existing BHC & 1 CHC (B & E) -Operate 1 existing CHC as BHC (F) -4 new BHCs (9,22,30,38)
<900,000	<746,100	285,900	706,500	740,000				
<1,000,000	<746,100	282,900	706,500	925,000	9 14 21 34 38 A F	-	G	-Close 3 existing BHC & 1 CHC (B, C,D & E) -Operate 1 existing CHC as BHC (F) -5 new BHCs (9,14,21,34,38)

Results (see Table 9) demonstrate that the current number and types of healthcare facilities are not optimal for Bamyan District. It is observed that more BHCs are built to replace the CHCs, as BHCs are cheaper to operate and build, as compared to a CHC.

With limited operating costs from NGOs and infrastructure support from donors, the possible solution for Bamyan District may be as follows:

- Downgrade CHCs into BHCs;
- Relocate BHCs to new locations with available infrastructure funding;
- Build BHCs in new locations with available infrastructure funding.

From Test Cases 2 and 3, we can conclude that existing locations B and E are not ideal for a healthcare facility. Village 9 is an ideal location for a new healthcare facility. It is also observed that location F is not an ideal location for a CHC. A BHC at location F may be more appropriate.

In our model, the services provided by the different types of healthcare facilities have not been taken into account. BHC may be more cost-effective when we consider

just the raw capacity of the people, but not the actual services the people require. Therefore, our model is suggesting building more BHCs (see Figure 7.)

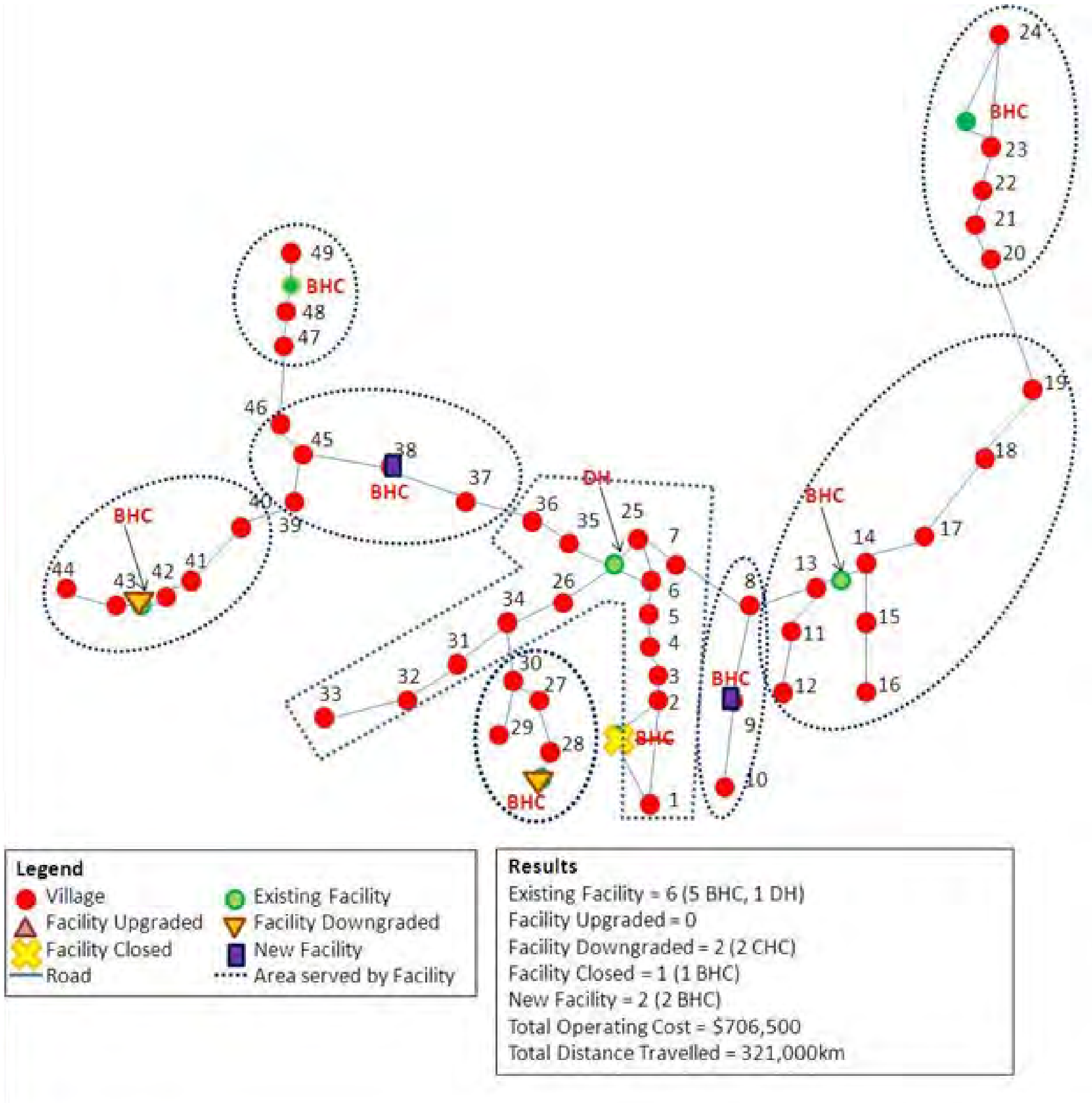

Figure 7. Scenario in Test Case 3 with limited operating budget (<$746,100) and infrastructure budget (<$400,000)

D. TEST CASE 4

In Test Case 4, we want to determine how the available operating budget and infrastructure budget affect the total traveled distance taken by the patients, and the number and type of healthcare facility locations.

Table 10. Total distance traveled based on the available operating and infrastructure budget for healthcare facilities (Excerpt from Appendix B)

Total traveled distance (thousands of km)		Infrastructure budget (thousands of $)										
		0	100	200	300	400	500	600	700	800	900	1000
Operating budget (thousands of $)	1000	385.2	385.2	342.9	342.9	301.2	301.2	266.1	266.1	240.45	240.45	223.2
	900	385.2	385.2	342.9	342.9	301.2	301.2	266.1	266.1	240.45	240.45	228.3
	800	385.2	385.2	342.9	342.9	301.2	301.2	282.3	282.3	267	267	257.55
	746.1	385.2	385.2	342.9	342.9	321	321	301.2	301.2	285.9	285.9	282.9
	700	385.2	385.2	361.8	361.8	342	342	326.7	326.7	314.55	314.55	311.55
	600	404.1	404.1	384.3	384.3	369	369	356.85	356.85	353.85	353.85	351.75
	500	578.7	578.7	552.9	552.9	537.6	537.6	534.6	534.6	534.6	534.6	534.6

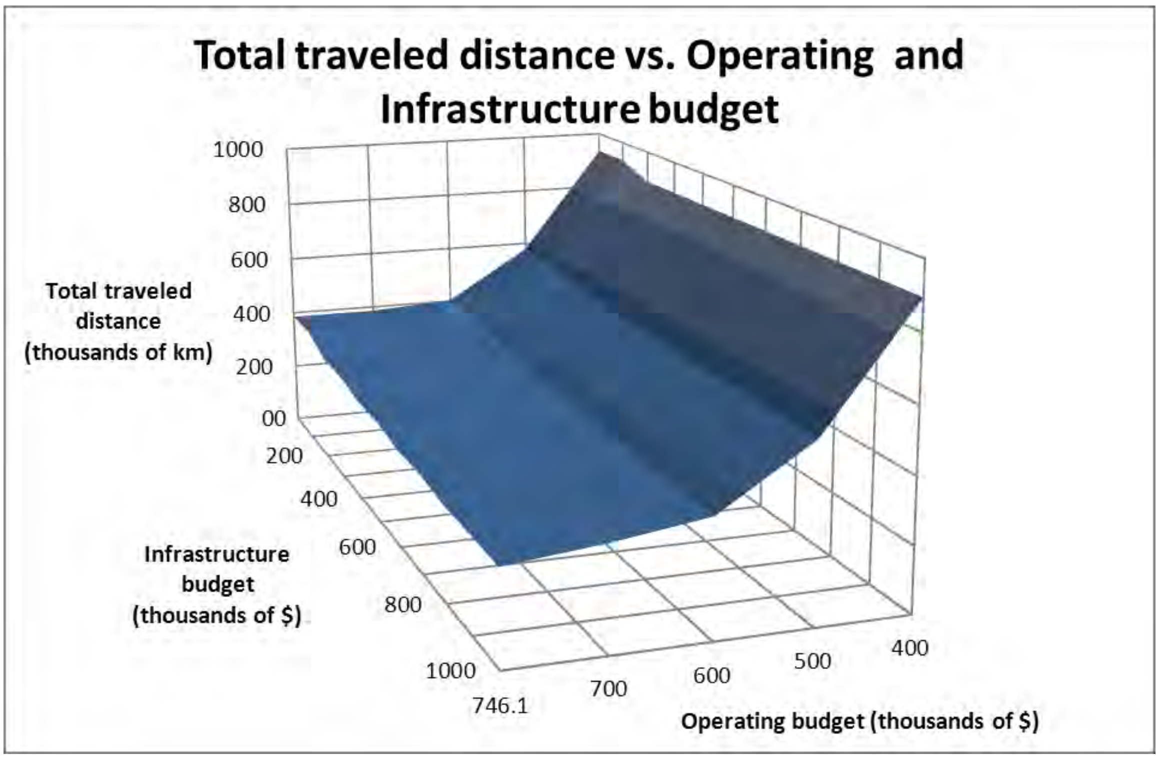

Figure 8. 3D Plot of total traveled distance vs. available budgets.

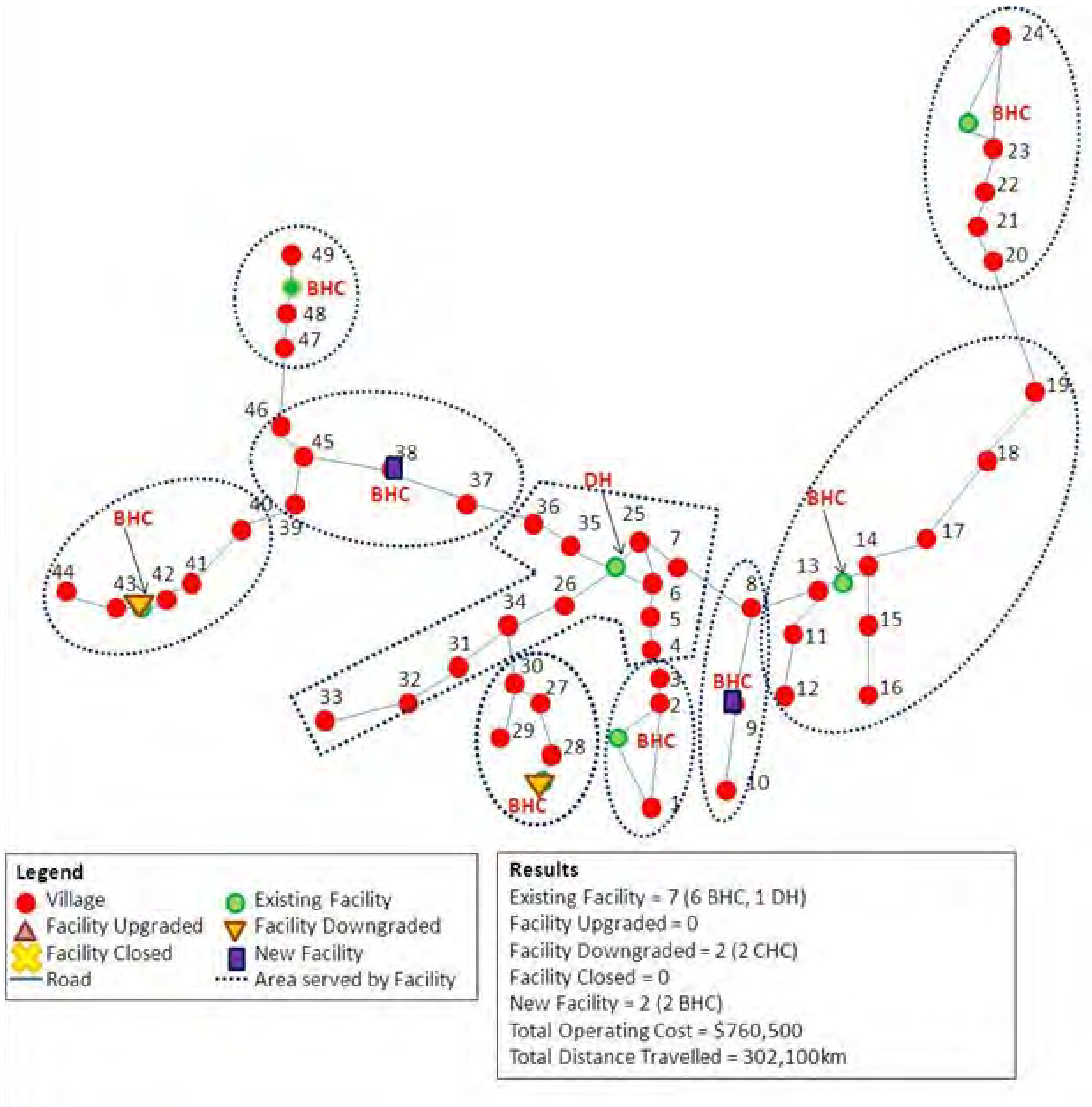

Figure 9. Scenario in Test Case 4 with increased operating cost (<$900,000) and infrastructure support (<$400,000)

From the results (see Table 10 and Figure 8), it is observed that with the increase of available funds for infrastructure or operations of the healthcare facilities, the total traveled distance is reduced. There are no feasible solutions if the available operating fund is reduced below $400,000. It is also observed from the results that donors have to contribute at least $200,000 in order to help reduce the total traveled distance.

We also observed that more BHCs are built to reduce the traveled distance when sufficient budget for infrastructure is available. The DH remains in its location at G throughout the test cases (see Figure 9).

E. TEST CASE 5

In this test case, we study how the acceptance level of the ethnicity group affects the number, type and operator's ethnicity group of healthcare facility types. We are assuming the operating funding is kept at the base value and there is no infrastructure budget.

Table 11. Type and number of healthcare facilities to be operated by the assigned ethnicity group based on the acceptance level of the ethnicity (Excerpt from Appendix C)

Acceptance level of ethnicity		Healthcare facility						Total distance traveled by ethnicity (km)		
A	B	Operated by ethnicity A			Operated by ethnicity B			A	B	Total
		BHC	CHC	DH	BHC	CHC	DH			
1	0.5	-	-	-	A B C D E F	-	G	308,160	77,040	385,200
1	0.6	-	-	-	A B C D E F	-	G	308,160	77,040	385,200
1	0.7	-	-	-	A B C D E F	-	G	308,160	77,040	385,200
0.9	0.5	C	-	G	A B D E F	-	-	351,300	100,305	451,605
0.9	0.6	C	F	G	A B D	E	-	335,844	110,244	446,088
0.9	0.7	A B D E	F	-	C	-	G	326,772	109,395	436,167
0.8	0.5	A B D E F	-	-	C	-	G	345,384	130,965	476,349
0.8	0.6	A B D E F	-	-	C	-	G	345,384	120,180	465,564
0.8	0.7	A B C D E F	-	-	-	-	G	323,544	126,846	450,390
0.7	0.5	A B C D E	F	-	-	-	G	331,236	160,050	491,286
0.7	0.6	A B C D E F	-	-	-	-	G	331,236	143,448	474,684
0.7	0.7	A B C D E	F	-	-	-	G	331,236	126,846	458,082
0.6	0.5	A B C D	E F	-	-	-	G	338,928	160,050	498,978
0.6	0.6	A B C D E F	-	-	-	-	G	338,928	143,448	482,376
0.6	0.7	A B C D E F	-	-	-	-	G	338,928	126,846	465,774

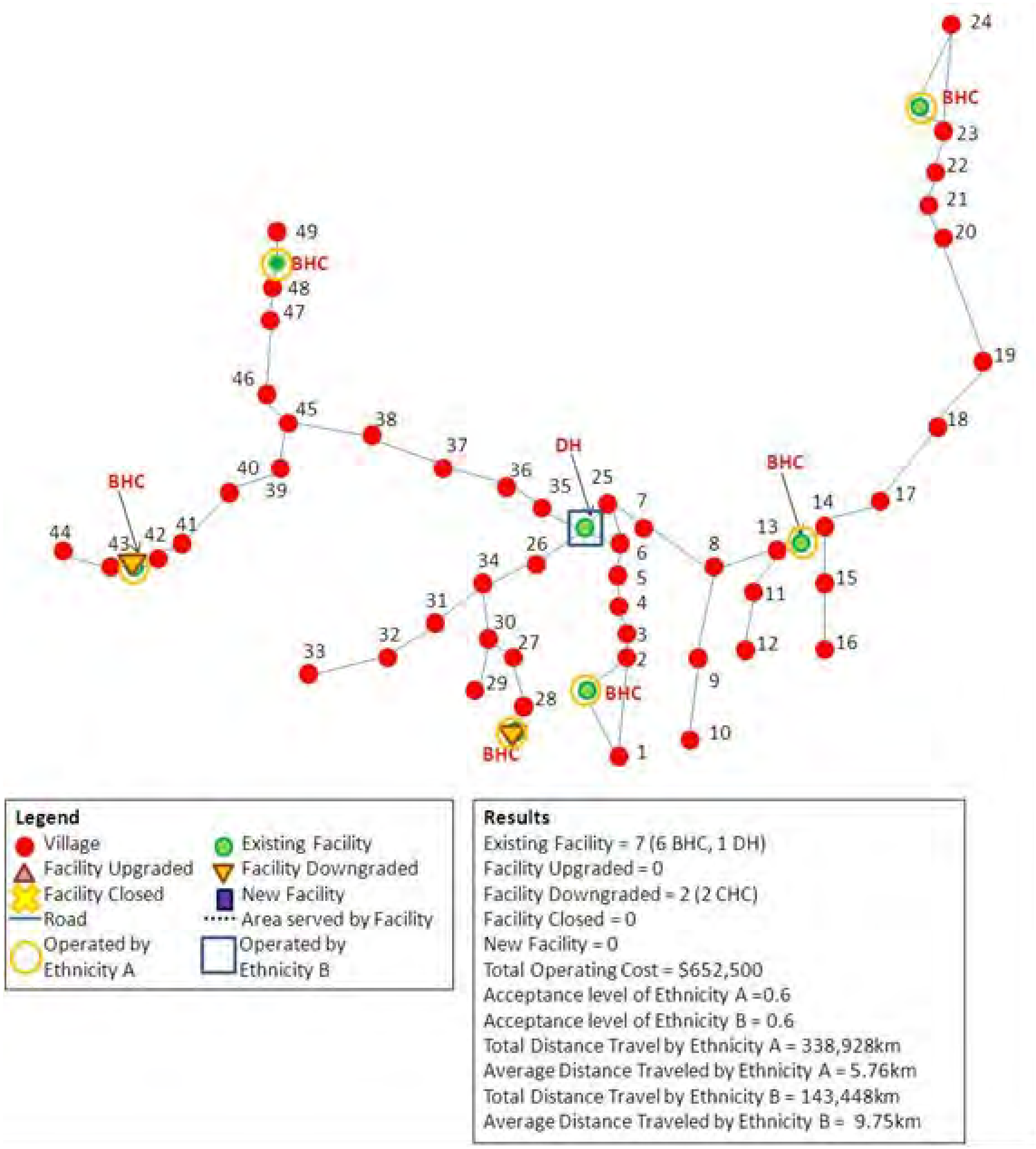

Figure 10. Scenario in Test Case 5 with both the ethnicity acceptance level to be 0.6.

The results (see Table 11) show that when the acceptance level of an ethnicity is much higher than the other, most of the healthcare facilities are operated by the ethnicity

with the lower acceptance level. This is due to the fact that the ethnicity with the higher acceptance level is more willing to go to healthcare facilities that are operated by a different ethnicity.

If the population of the major ethnicity is very large, more healthcare facilities would be operated by its own ethnicity, regardless of the acceptance level. In our case, where 80 percent of the population belongs to the major ethnicity group, more healthcare facilities are operated by the major ethnicity, even though the acceptance level is high. These facilities may still serve the minor ethnicity population that is willing to go to the facility that is not operated by its own ethnicity. The rest of minor ethnicity population will have to travel further to a medical facility.

The population of the minority ethnicity would operate a single facility that has a large capacity. In our test case, it is observed that the DH is operated by ethnicity B. Though the population of the minor ethnicity is small, it is still rational to allow ethnicity B to operate the hospital, as the acceptance level of the major ethnicity is high. The results show that the patients from the minority ethnicity may have to travel further to seek medical attention at a DH, but this is the only facility operated by its ethnicity. In a scenario that both ethnicity acceptance levels are about 60 to 70 percent (see Figure 10), a patient of ethnicity A travels about 5.76 km to go to a healthcare facility, whereas a patient of ethnicity B travels about 9.75 km.

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VI. CONCLUSION AND RECOMMENDATIONS

In this chapter, we highlight the key conclusions and recommendations that are derived from the models presented in this thesis.

A. EXTENDED HEALTHCARE FACILITIES LOCATION MODEL

We have formulated and solved a linear, mixed-integer location model to provide guidance in locating healthcare facilities. The model takes into account physical limitations, such as the operating cost, infrastructure cost, capacity of the healthcare facilities and other operational constraints in order to minimize the total distance traveled by the patients.

The model is able to help decision makers to identify which optimal type of healthcare facility should be operated at which location, based on the available operating cost and infrastructure budget.

The available operating cost is limited to the base cost value in Test Cases 2 and 3, which model the available funding the NGOs have to operate the healthcare facilities. Limited operating cost is one of the two limiting factors in reducing the total traveled distance in our test cases.

The available infrastructure budget has been made available in Test Cases 3 and 4, where upgrading of existing facilities or building new facilities at new locations is made possible. Infrastructure budget is another limiting factor for reducing the total traveled distance.

With the infrastructure cost made available, the DoPH is allowed to build new facilities to reduce the total distance traveled by the patients. Without the infrastructure support from donors, the DoPH will not be able to open any new facilities to reduce total traveled distance. The increase in operating funding would allow the DoPH to expand its clinics in existing locations. Expanding the clinics would not help in reducing the distance traveled. Both infrastructure and operating cost would have to be present to make an impact on the reduction of distance traveled.

B. ETHNICITY HEALTHCARE FACILITIES LOCATION MODEL

This model takes into account the ethnicity issues that the patients will face when visiting a healthcare facility.

The model is able to help decision makers to identify which optimal type of healthcare facility is must be operated by which ethnicity group in order to minimize the total distance traveled by the patients to access a healthcare facility.

The model shows that the population of the major ethnicty group traveled shorter distances to arrive to a healthcare facility as compared to the minor ethincity. More healthcare facilities are operated by the major ethnicity, even though the acceptance level of the major ethincity is high. These facilities may still serve members of the minor ethnicty population who are willing to go to the facility that is not operated by its own ethicity.

The results also show that the current plan of four BHCs, two CHCs and one DH is not optimal. BHCs replace CHCs in most of the results. This might be due to the fact that a BHC may be more cost effective when we consider just the raw capacity of the people, but not the actual services the people require.

C. RECOMMENDATIONS

Future analyses and testing may improve the model and data in order to achieve further realism. Some possible areas for research include:

- Employing more accurate data for the population, ethnicity and location of demand nodes.
- Incorporate more realism into the types of clinics. Types of services provided by the clinics can be incorporated into the model, as services in a CHC may not be available in the BHC. (Süral, 2005)
- Incorporating the multiobjective function as in the developed model. Currently, the aim is to minimize the total traveled distance. We seek to minimize the total budget and transportation cost to optimize the location of the clinics. The model might include some fairness constraint for the distance traveled by the different ethnicity. In our current model, some of the patients are traveling much longer distance than others.

APPENDIX A. TRAVELING DISTANCE BETWEEN THE NODES

Distance	Nodes																																																						
Nodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	A	B	C	D	E	F	G
1		5	6	7.2	8.4	9.7	14.1	18.1	22.6	26.6	22.1	24.6	25.1	27.1	30.1	33.1	30.4	34.4	38.4	44.4	46.1	47.5	49.2	55.2	11.7	12.7	19.1	21.5	20.2	17.7	18.3	21	25.1	15.3	14.7	16.7	20.4	23.9	28.4	31.4	35.9	37.2	38.9	41.9	28.9	29.9	33.9	35.2	37.9	36.4	4	50.9	26.1	21.9	37.9	11.2
2	5		1	2.2	3.4	4.7	9.1	13.1	17.6	21.6	17.1	19.6	20.1	22.1	25.1	28.1	25.4	29.4	33.4	39.4	41.1	42.5	44.2	50.2	6.7	7.7	14.1	16.5	15.2	12.7	13.3	16	20.1	10.3	9.7	11.7	15.4	18.9	23.4	26.4	30.9	32.2	33.9	36.9	23.9	24.9	28.9	30.2	32.9	31.4	2.5	45.9	21.1	16.9	32.9	6.2
3	6	1		1.2	2.4	3.7	8.1	12.1	16.6	20.6	16.1	18.6	19.1	21.1	24.1	27.1	24.4	28.4	32.4	38.4	40.1	41.5	43.2	49.2	5.7	6.7	13.1	15.5	14.2	11.7	12.3	15	19.1	9.3	8.7	10.7	14.4	17.9	22.4	25.4	29.9	31.2	32.9	35.9	22.9	23.9	27.9	29.2	31.9	30.4	3.5	44.9	20.1	15.9	31.9	5.2
4	7.2	2.2	1.2		1.2	2.5	6.9	10.9	15.4	19.4	14.9	17.4	17.9	19.9	22.9	25.9	23.2	27.2	31.2	37.2	38.9	40.3	42	48	4.5	5.5	11.9	14.3	13	10.5	11.1	13.8	17.9	8.1	7.5	9.5	13.2	16.7	21.2	24.2	28.7	30	31.7	34.7	21.7	22.7	26.7	28	30.7	29.2	4.7	43.7	18.9	14.7	30.7	4
5	8.4	3.4	2.4	1.2		1.3	5.7	9.7	14.2	18.2	13.7	16.2	16.7	18.7	21.7	24.7	22	26	30	36	37.7	39.1	40.8	46.8	3.3	4.3	10.7	13.1	11.8	9.3	9.9	12.6	16.7	6.9	6.3	8.3	12	15.5	20	23	27.5	28.8	30.5	33.5	20.5	21.5	25.5	26.8	29.5	28	5.9	42.5	17.7	13.5	29.5	2.8
6	9.7	4.7	3.7	2.5	1.3		4.4	8.4	12.9	16.9	12.4	14.9	15.4	17.4	20.4	23.4	20.7	24.7	28.7	34.7	36.4	37.8	39.5	45.5	2	3	9.4	11.8	10.5	8	8.6	11.3	15.4	5.6	5	7	10.7	14.2	18.7	21.7	26.2	27.5	29.2	32.2	19.2	20.2	24.2	25.5	28.2	26.7	7.2	41.2	16.4	12.2	28.2	1.5
7	14.1	9.1	8.1	6.9	5.7	4.4		4	8.5	12.5	8	10.5	11	13	16	19	16.3	20.3	24.3	30.3	32	33.4	35.1	41.1	2.4	5.4	11.8	14.2	12.9	10.4	11	13.7	17.8	8	5.4	7.4	11.1	14.6	19.1	22.1	26.6	27.9	29.6	32.6	19.6	20.6	24.6	25.9	28.6	27.1	11.6	36.8	12	14.6	28.6	3.9
8	18.1	13.1	12.1	10.9	9.7	8.4	4		4.5	8.5	4	6.5	7	9	12	15	12.3	16.3	20.3	26.3	28	29.4	31.1	37.1	6.4	9.4	15.8	18.2	16.9	14.4	15	17.7	21.8	12	9.4	11.4	15.1	18.6	23.1	26.1	30.6	31.9	33.6	36.6	23.6	24.6	28.6	29.9	32.6	31.1	15.6	32.8	8	18.6	32.6	7.9
9	22.6	17.6	16.6	15.4	14.2	12.9	8.5	4.5		4	8.5	11	11.5	13.5	16.5	19.5	16.8	20.8	24.8	30.8	32.5	33.9	35.6	41.6	10.9	13.9	20.3	22.7	21.4	18.9	19.5	22.2	26.3	16.5	13.9	15.9	19.6	23.1	27.6	30.6	35.1	36.4	38.1	41.1	28.1	29.1	33.1	34.4	37.1	35.6	20.1	37.3	12.5	23.1	37.1	12.4
10	26.6	21.6	20.6	19.4	18.2	16.9	12.5	8.5	4		12.5	15	15.5	17.5	20.5	23.5	20.8	24.8	28.8	34.8	36.5	37.9	39.6	45.6	14.9	17.9	24.3	26.7	25.4	22.9	23.5	26.2	30.3	20.5	17.9	19.9	23.6	27.1	31.6	34.6	39.1	40.4	42.1	45.1	32.1	33.1	37.1	38.4	41.1	39.6	24.1	41.3	16.5	27.1	41.1	16.4
11	22.1	17.1	16.1	14.9	13.7	12.4	8	4	8.5	12.5		2.5	3	5	8	11	8.3	12.3	16.3	22.3	24	25.4	27.1	33.1	10.4	13.4	19.8	22.2	20.9	18.4	19	21.7	25.8	16	13.4	15.4	19.1	22.6	27.1	30.1	34.6	35.9	37.6	40.6	27.6	28.6	32.6	33.9	36.6	35.1	19.6	28.8	4	22.6	36.6	11.9
12	24.6	19.6	18.6	17.4	16.2	14.9	10.5	6.5	11	15	2.5		5.5	7.5	10.5	13.5	10.8	14.8	18.8	24.8	26.5	27.9	29.6	35.6	12.9	15.9	22.3	24.7	23.4	20.9	21.5	24.2	28.3	18.5	15.9	17.9	21.6	25.1	29.6	32.6	37.1	38.4	40.1	43.1	30.1	31.1	35.1	36.4	39.1	37.6	22.1	31.3	6.5	25.1	39.1	14.4
13	25.1	20.1	19.1	17.9	16.7	15.4	11	7	11.5	15.5	3	5.5		2	5	8	5.3	9.3	13.3	19.3	21	22.4	24.1	30.1	13.4	16.4	22.8	25.2	23.9	21.4	22	24.7	28.8	19	16.4	18.4	22.1	25.6	30.1	33.1	37.6	38.9	40.6	43.6	30.6	31.6	35.6	36.9	39.6	38.1	22.6	25.8	1	25.6	39.6	14.9
14	27.1	22.1	21.1	19.9	18.7	17.4	13	9	13.5	17.5	5	7.5	2		3	6	3.3	7.3	11.3	17.3	19	20.4	22.1	28.1	15.4	18.4	24.8	27.2	25.9	23.4	24	26.7	30.8	21	18.4	20.4	24.1	27.6	32.1	35.1	39.6	40.9	42.6	45.6	32.6	33.6	37.6	38.9	41.6	40.1	24.6	23.8	1	27.6	41.6	16.9
15	30.1	25.1	24.1	22.9	21.7	20.4	16	12	16.5	20.5	8	10.5	5	3		3	6.3	10.3	14.3	20.3	22	23.4	25.1	31.1	18.4	21.4	27.8	30.2	28.9	26.4	27	29.7	33.8	24	21.4	23.4	27.1	30.6	35.1	38.1	42.6	43.9	45.6	48.6	35.6	36.6	40.6	41.9	44.6	43.1	27.6	26.8	4	30.6	44.6	19.9
16	33.1	28.1	27.1	25.9	24.7	23.4	19	15	19.5	23.5	11	13.5	8	6	3		9.3	13.3	17.3	23.3	25	26.4	28.1	34.1	21.4	24.4	30.8	33.2	31.9	29.4	30	32.7	36.8	27	24.4	26.4	30.1	33.6	38.1	41.1	45.6	46.9	48.6	51.6	38.6	39.6	43.6	44.9	47.6	46.1	30.6	29.8	7	33.6	47.6	22.9
17	30.4	25.4	24.4	23.2	22	20.7	16.3	12.3	16.8	20.8	8.3	10.8	5.3	3.3	6.3	9.3		4	8	14	15.7	17.1	18.8	24.8	18.7	21.7	28.1	30.5	29.2	26.7	27.3	30	34.1	24.3	21.7	23.7	27.4	30.9	35.4	38.4	42.9	44.2	45.9	48.9	35.9	36.9	40.9	42.2	44.9	43.4	27.9	20.5	4.3	30.9	44.9	20.2
18	34.4	29.4	28.4	27.2	26	24.7	20.3	16.3	20.8	24.8	12.3	14.8	9.3	7.3	10.3	13.3	4		4	10	11.7	13.1	14.8	20.8	22.7	25.7	32.1	34.5	33.2	30.7	31.3	34	38.1	28.3	25.7	27.7	31.4	34.9	39.4	42.4	46.9	48.2	49.9	52.9	39.9	40.9	44.9	46.2	48.9	47.4	31.9	16.5	8.3	34.9	48.9	24.2
19	38.4	33.4	32.4	31.2	30	28.7	24.3	20.3	24.8	28.8	16.3	18.8	13.3	11.3	14.3	17.3	8	4		6	7.7	9.1	10.8	16.8	26.7	29.7	36.1	38.5	37.2	34.7	35.3	38	42.1	32.3	29.7	31.7	35.4	38.9	43.4	46.4	50.9	52.2	53.9	56.9	43.9	44.9	48.9	50.2	52.9	51.4	35.9	12.5	12.3	38.9	52.9	28.2
20	44.4	39.4	38.4	37.2	36	34.7	30.3	26.3	30.8	34.8	22.3	24.8	19.3	17.3	20.3	23.3	14	10	6		1.7	3.1	4.8	10.8	32.7	35.7	42.1	44.5	43.2	40.7	41.3	44	48.1	38.3	35.7	37.7	41.4	44.9	49.4	52.4	56.9	58.2	59.9	62.9	49.9	50.9	54.9	56.2	58.9	57.4	41.9	6.5	18.3	44.9	58.9	34.2
21	46.1	41.1	40.1	38.9	37.7	36.4	32	28	32.5	36.5	24	26.5	21	19	22	25	15.7	11.7	7.7	1.7		1.4	3.1	9.1	34.4	37.4	43.8	46.2	44.9	42.4	43	45.7	49.8	40	37.4	39.4	43.1	46.6	51.1	54.1	58.6	59.9	61.6	64.6	51.6	52.6	56.6	57.9	60.6	59.1	43.6	4.8	20	46.6	60.6	35.9
22	47.5	42.5	41.5	40.3	39.1	37.8	33.4	29.4	33.9	37.9	25.4	27.9	22.4	20.4	23.4	26.4	17.1	13.1	9.1	3.1	1.4		1.7	7.7	35.8	38.8	45.2	47.6	46.3	43.8	44.4	47.1	51.2	41.4	38.8	40.8	44.5	48	52.5	55.5	60	61.3	63	66	53	54	58	59.3	62	60.5	45	3.4	21.4	48	62	37.3
23	49.2	44.2	43.2	42	40.8	39.5	35.1	31.1	35.6	39.6	27.1	29.6	24.1	22.1	25.1	28.1	18.8	14.8	10.8	4.8	3.1	1.7		6	37.5	40.5	46.9	49.3	48	45.5	46.1	48.8	52.9	43.1	40.5	42.5	46.2	49.7	54.2	57.2	61.7	63	64.7	67.7	54.7	55.7	59.7	61	63.7	62.2	46.7	1.7	23.1	49.7	63.7	39
24	55.2	50.2	49.2	48	46.8	45.5	41.1	37.1	41.6	45.6	33.1	35.6	30.1	28.1	31.1	34.1	24.8	20.8	16.8	10.8	9.1	7.7	6		43.5	46.5	52.9	55.3	54	51.5	52.1	54.8	58.9	49.1	46.5	48.5	52.2	55.7	60.2	63.2	67.7	69	70.7	73.7	60.7	61.7	65.7	67	69.7	68.2	52.7	4.5	29.1	55.7	69.7	45
25	11.7	6.7	5.7	4.5	3.3	2	2.4	6.4	10.9	14.9	10.4	12.9	13.4	15.4	18.4	21.4	18.7	22.7	26.7	32.7	34.4	35.8	37.5	43.5		3	9.4	11.8	10.5	8	8.6	11.3	15.4	5.6	3	5	8.7	12.2	16.7	19.7	24.2	25.5	27.2	30.2	17.2	18.2	22.2	23.5	26.2	24.7	9.2	39.2	14.4	12.2	26.2	1.5
26	12.7	7.7	6.7	5.5	4.3	3	5.4	9.4	13.9	17.9	13.4	15.9	16.4	18.4	21.4	24.4	21.7	25.7	29.7	35.7	37.4	38.8	40.5	46.5	3		6.4	8.8	7.5	5	5.6	8.3	12.4	2.6	6	8	11.7	15.2	19.7	22.7	27.2	28.5	30.2	33.2	20.2	21.2	25.2	26.5	29.2	27.7	10.2	42.2	17.4	9.2	29.2	1.5
27	19.1	14.1	13.1	11.9	10.7	9.4	11.8	15.8	20.3	24.3	19.8	22.3	22.8	24.8	27.8	30.8	28.1	32.1	36.1	42.1	43.8	45.2	46.9	52.9	9.4	6.4		2.4	3.9	1.4	6.8	9.5	13.6	3.8	12.4	14.4	18.1	21.6	26.1	29.1	33.6	34.9	36.6	39.6	26.6	27.6	31.6	32.9	35.6	34.1	16.6	48.6	23.8	2.8	35.6	7.9
28	21.5	16.5	15.5	14.3	13.1	11.8	14.2	18.2	22.7	26.7	22.2	24.7	25.2	27.2	30.2	33.2	30.5	34.5	38.5	44.5	46.2	47.6	49.3	55.3	11.8	8.8	2.4		6.3	3.8	9.2	11.9	16	6.2	14.8	16.8	20.5	24	28.5	31.5	36	37.3	39	42	29	30	34	35.3	38	36.5	19	51	26.2	0.4	38	10.3
29	20.2	15.2	14.2	13	11.8	10.5	12.9	16.9	21.4	25.4	20.9	23.4	23.9	25.9	28.9	31.9	29.2	33.2	37.2	43.2	44.9	46.3	48	54	10.5	7.5	3.9	6.3		2.5	7.9	10.6	14.7	4.9	13.5	15.5	19.2	22.7	27.2	30.2	34.7	36	37.7	40.7	27.7	28.7	32.7	34	36.7	35.2	17.7	49.7	24.9	6.7	36.7	9
30	17.7	12.7	11.7	10.5	9.3	8	10.4	14.4	18.9	22.9	18.4	20.9	21.4	23.4	26.4	29.4	26.7	30.7	34.7	40.7	42.4	43.8	45.5	51.5	8	5	1.4	3.8	2.5		5.4	8.1	12.2	2.4	11	13	16.7	20.2	24.7	27.7	32.2	33.5	35.2	38.2	25.2	26.2	30.2	31.5	34.2	32.7	15.2	47.2	22.4	4.2	34.2	6.5
31	18.3	13.3	12.3	11.1	9.9	8.6	11	15	19.5	23.5	19	21.5	22	24	27	30	27.3	31.3	35.3	41.3	43	44.4	46.1	52.1	8.6	5.6	6.8	9.2	7.9	5.4		2.7	6.8	3	11.6	13.6	17.3	20.8	25.3	28.3	32.8	34.1	35.8	38.8	25.8	26.8	30.8	32.1	34.8	33.3	15.8	47.8	23	9.6	34.8	7.1
32	21	16	15	13.8	12.6	11.3	13.7	17.7	22.2	26.2	21.7	24.2	24.7	26.7	29.7	32.7	30	34	38	44	45.7	47.1	48.8	54.8	11.3	8.3	9.5	11.9	10.6	8.1	2.7		4.1	5.7	14.3	16.3	20	23.5	28	31	35.5	36.8	38.5	41.5	28.5	29.5	33.5	34.8	37.5	36	18.5	50.5	25.7	12.3	37.5	9.8
33	25.1	20.1	19.1	17.9	16.7	15.4	17.8	21.8	26.3	30.3	25.8	28.3	28.8	30.8	33.8	36.8	34.1	38.1	42.1	48.1	49.8	51.2	52.9	58.9	15.4	12.4	13.6	16	14.7	12.2	6.8	4.1		9.8	18.4	20.4	24.1	27.6	32.1	35.1	39.6	40.9	42.6	45.6	32.6	33.6	37.6	38.9	41.6	40.1	22.6	54.6	29.8	16.4	41.6	13.9
34	15.3	10.3	9.3	8.1	6.9	5.6	8	12	16.5	20.5	16	18.5	19	21	24	27	24.3	28.3	32.3	38.3	40	41.4	43.1	49.1	5.6	2.6	3.8	6.2	4.9	2.4	3	5.7	9.8		8.6	10.6	14.3	17.8	22.3	25.3	29.8	31.1	32.8	35.8	22.8	23.8	27.8	29.1	31.8	30.3	12.8	44.8	20	6.6	31.8	4.1
35	14.7	9.7	8.7	7.5	6.3	5	5.4	9.4	13.9	17.9	13.4	15.9	16.4	18.4	21.4	24.4	21.7	25.7	29.7	35.7	37.4	38.8	40.5	46.5	3	6	12.4	14.8	13.5	11	11.6	14.3	18.4	8.6		2	5.7	9.2	13.7	16.7	21.2	22.5	24.2	27.2	14.2	15.2	19.2	20.5	23.2	21.7	12.2	42.2	17.4	15.2	23.2	4.5
36	16.7	11.7	10.7	9.5	8.3	7	7.4	11.4	15.9	19.9	15.4	17.9	18.4	20.4	23.4	26.4	23.7	27.7	31.7	37.7	39.4	40.8	42.5	48.5	5	8	14.4	16.8	15.5	13	13.6	16.3	20.4	10.6	2		3.7	7.2	11.7	14.7	19.2	20.5	22.2	25.2	12.2	13.2	17.2	18.5	21.2	19.7	14.2	44.2	19.4	17.2	21.2	6.5
37	20.4	15.4	14.4	13.2	12	10.7	11.1	15.1	19.6	23.6	19.1	21.6	22.1	24.1	27.1	30.1	27.4	31.4	35.4	41.4	43.1	44.5	46.2	52.2	8.7	11.7	18.1	20.5	19.2	16.7	17.3	20	24.1	14.3	5.7	3.7		3.5	8	11	15.5	16.8	18.5	21.5	8.5	9.5	13.5	14.8	17.5	16	17.9	47.9	23.1	20.9	17.5	10.2
38	23.9	18.9	17.9	16.7	15.5	14.2	14.6	18.6	23.1	27.1	22.6	25.1	25.6	27.6	30.6	33.6	30.9	34.9	38.9	44.9	46.6	48	49.7	55.7	12.2	15.2	21.6	24	22.7	20.2	20.8	23.5	27.6	17.8	9.2	7.2	3.5		4.5	7.5	12	13.3	15	18	5	6	10	11.3	14	12.5	21.4	51.4	26.6	24.4	14	13.7
39	28.4	23.4	22.4	21.2	20	18.7	19.1	23.1	27.6	31.6	27.1	29.6	30.1	32.1	35.1	38.1	35.4	39.4	43.4	49.4	51.1	52.5	54.2	60.2	16.7	19.7	26.1	28.5	27.2	24.7	25.3	28	32.1	22.3	13.7	11.7	8	4.5		3	7.5	8.8	10.5	13.5	9.5	10.5	14.5	15.8	18.5	17	25.9	55.9	31.1	28.9	9.5	18.2
40	31.4	26.4	25.4	24.2	23	21.7	22.1	26.1	30.6	34.6	30.1	32.6	33.1	35.1	38.1	41.1	38.4	42.4	46.4	52.4	54.1	55.5	57.2	63.2	19.7	22.7	29.1	31.5	30.2	27.7	28.3	31	35.1	25.3	16.7	14.7	11	7.5	3		4.5	5.8	7.5	10.5	12.5	13.5	17.5	18.8	21.5	20	28.9	58.9	34.1	31.9	6.5	21.2
41	35.9	30.9	29.9	28.7	27.5	26.2	26.6	30.6	35.1	39.1	34.6	37.1	37.6	39.6	42.6	45.6	42.9	46.9	50.9	56.9	58.6	60	61.7	67.7	24.2	27.2	33.6	36	34.7	32.2	32.8	35.5	39.6	29.8	21.2	19.2	15.5	12	7.5	4.5		1.3	3	6	17	18	22	23.3	26	24.5	33.4	63.4	38.6	36.4	2	25.7
42	37.2	32.2	31.2	30	28.8	27.5	27.9	31.9	36.4	40.4	35.9	38.4	38.9	40.9	43.9	46.9	44.2	48.2	52.2	58.2	59.9	61.3	63	69	25.5	28.5	34.9	37.3	36	33.5	34.1	36.8	40.9	31.1	22.5	20.5	16.8	13.3	8.8	5.8	1.3		1.7	4.7	18.3	19.3	23.3	24.6	27.3	25.8	34.7	64.7	39.9	37.7	0.7	27
43	38.9	33.9	32.9	31.7	30.5	29.2	29.6	33.6	38.1	42.1	37.6	40.1	40.6	42.6	45.6	48.6	45.9	49.9	53.9	59.9	61.6	63	64.7	70.7	27.2	30.2	36.6	39	37.7	35.2	35.8	38.5	42.6	32.8	24.2	22.2	18.5	15	10.5	7.5	3	1.7		3	20	21	25	26.3	29	27.5	36.4	66.4	41.6	39.4	1	28.7
44	41.9	36.9	35.9	34.7	33.5	32.2	32.6	36.6	41.1	45.1	40.6	43.1	43.6	45.6	48.6	51.6	48.9	52.9	56.9	62.9	64.6	66	67.7	73.7	30.2	33.2	39.6	42	40.7	38.2	38.8	41.5	45.6	35.8	27.2	25.2	21.5	18	13.5	10.5	6	4.7	3		23	24	28	29.3	32	30.5	39.4	69.4	44.6	42.4	4	31.7
45	28.9	23.9	22.9	21.7	20.5	19.2	19.6	23.6	28.1	32.1	27.6	30.1	30.6	32.6	35.6	38.6	35.9	39.9	43.9	49.9	51.6	53	54.7	60.7	17.2	20.2	26.6	29	27.7	25.2	25.8	28.5	32.6	22.8	14.2	12.2	8.5	5	9.5	12.5	17	18.3	20	23		1	5	6.3	9	7.5	26.4	56.4	31.6	29.4	19	18.7
46	29.9	24.9	23.9	22.7	21.5	20.2	20.6	24.6	29.1	33.1	28.6	31.1	31.6	33.6	36.6	39.6	36.9	40.9	44.9	50.9	52.6	54	55.7	61.7	18.2	21.2	27.6	30	28.7	26.2	26.8	29.5	33.6	23.8	15.2	13.2	9.5	6	10.5	13.5	18	19.3	21	24	1		4	5.3	8	6.5	27.4	57.4	32.6	30.4	20	19.7
47	33.9	28.9	27.9	26.7	25.5	24.2	24.6	28.6	33.1	37.1	32.6	35.1	35.6	37.6	40.6	43.6	40.9	44.9	48.9	54.9	56.6	58	59.7	65.7	22.2	25.2	31.6	34	32.7	30.2	30.8	33.5	37.6	27.8	19.2	17.2	13.5	10	14.5	17.5	22	23.3	25	28	5	4		1.3	4	2.5	31.4	61.4	36.6	34.4	24	23.7
48	35.2	30.2	29.2	28	26.8	25.5	25.9	29.9	34.4	38.4	33.9	36.4	36.9	38.9	41.9	44.9	42.2	46.2	50.2	56.2	57.9	59.3	61	67	23.5	26.5	32.9	35.3	34	31.5	32.1	34.8	38.9	29.1	20.5	18.5	14.8	11.3	15.8	18.8	23.3	24.6	26.3	29.3	6.3	5.3	1.3		2.7	1.2	32.7	62.7	37.9	35.7	25.3	25
49	37.9	32.9	31.9	30.7	29.5	28.2	28.6	32.6	37.1	41.1	36.6	39.1	39.6	41.6	44.6	47.6	44.9	48.9	52.9	58.9	60.6	62	63.7	69.7	26.2	29.2	35.6	38	36.7	34.2	34.8	37.5	41.6	31.8	23.2	21.2	17.5	14	18.5	21.5	26	27.3	29	32	9	8	4	2.7		1.5	35.4	65.4	40.6	38.4	28	27.7
A	36.4	31.4	30.4	29.2	28	26.7	27.1	31.1	35.6	39.6	35.1	37.6	38.1	40.1	43.1	46.1	43.4	47.4	51.4	57.4	59.1	60.5	62.2	68.2	24.7	27.7	34.1	36.5	35.2	32.7	33.3	36	40.1	30.3	21.7	19.7	16	12.5	17	20	24.5	25.8	27.5	30.5	7.5	6.5	2.5	1.2	1.5		33.9	63.9	39.1	36.9	26.5	26.2
B	4	2.5	3.5	4.7	5.9	7.2	11.6	15.6	20.1	24.1	19.6	22.1	22.6	24.6	27.6	30.6	27.9	31.9	35.9	41.9	43.6	45	46.7	52.7	9.2	10.2	16.6	19	17.7	15.2	15.8	18.5	22.6	12.8	12.2	14.2	17.9	21.4	25.9	28.9	33.4	34.7	36.4	39.4	26.4	27.4	31.4	32.7	35.4	33.9		48.4	23.6	19.4	35.4	8.7
C	50.9	45.9	44.9	43.7	42.5	41.2	36.8	32.8	37.3	41.3	28.8	31.3	25.8	23.8	26.8	29.8	20.5	16.5	12.5	6.5	4.8	3.4	1.7	4.5	39.2	42.2	48.6	51	49.7	47.2	47.8	50.5	54.6	44.8	42.2	44.2	47.9	51.4	55.9	58.9	63.4	64.7	66.4	69.4	56.4	57.4	61.4	62.7	65.4	63.9	48.4		24.8	51.4	65.4	40.7
D	26.1	21.1	20.1	18.9	17.7	16.4	12	8	12.5	16.5	4	6.5	1	1	4	7	4.3	8.3	12.3	18.3	20	21.4	23.1	29.1	14.4	17.4	23.8	26.2	24.9	22.4	23	25.7	29.8	20	17.4	19.4	23.1	26.6	31.1	34.1	38.6	39.9	41.6	44.6	31.6	32.6	36.6	37.9	40.6	39.1	23.6	24.8		26.6	40.6	15.9
E	21.9	16.9	15.9	14.7	13.5	12.2	14.6	18.6	23.1	27.1	22.6	25.1	25.6	27.6	30.6	33.6	30.9	34.9	38.9	44.9	46.6	48	49.7	55.7	12.2	9.2	2.8	0.4	6.7	4.2	9.6	12.3	16.4	6.6	15.2	17.2	20.9	24.4	28.9	31.9	36.4	37.7	39.4	42.4	29.4	30.4	34.4	35.7	38.4	36.9	19.4	51.4	26.6		38.4	10.7
F	37.9	32.9	31.9	30.7	29.5	28.2	28.6	32.6	37.1	41.1	36.6	39.1	39.6	41.6	44.6	47.6	44.9	48.9	52.9	58.9	60.6	62	63.7	69.7	26.2	29.2	35.6	38	36.7	34.2	34.8	37.5	41.6	31.8	23.2	21.2	17.5	14	9.5	6.5	2	0.7	1	4	19	20	24	25.3	28	26.5	35.4	65.4	40.6	38.4		27.7
G	11.2	6.2	5.2	4	2.8	1.5	3.9	7.9	12.4	16.4	11.9	14.4	14.9	16.9	19.9	22.9	20.2	24.2	28.2	34.2	35.9	37.3	39	45	1.5	1.5	7.9	10.3	9	6.5	7.1	9.8	13.9	4.1	4.5	6.5	10.2	13.7	18.2	21.2	25.7	27	28.7	31.7	18.7	19.7	23.7	25	27.7	26.2	8.7	40.7	15.9	10.7	27.7	

This appendix shows the traveling distance (km) between the nodes.

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APPENDIX B. TYPES AND LOCATIONS OF HEALTHCARE FACILITIES TO BE BUILT

Total traveled distance (thousand of km)		Facility Location	Infrastructure budget (thousands of $)									
			0	100	200	300	400	500	600	700	800	900
Operating budget (thousands of $)	1000	BHC	A B C D F	A B C D F	9 A B C D E F	9 A B C D E F	9 38 A B C D E F	9 38 A B C D E F	9 32 38 A B C D	9 32 38 A B C D	9 19 32 38 A B C D	9 19 32 38 A B C D
		CHC	E	E	-	-	-	-	E F	E F	E F	E F
		DH	G	G	G	G	G	G	G	G	G	G
		Distance	**385.2**	**385.2**	**342.9**	**342.9**	**301.2**	**301.2**	**266.1**	**266.1**	**240.45**	**240.45**
	900	BHC	A B C D F	A B C D F	9 A B C D E F	9 A B C D E F	9 38 A B C D E F	9 38 A B C D E F	9 32 38 A B C D F	9 32 38 A B C D F	9 19 32 38 A B C D E F	9 19 32 38 A B C D E F
		CHC	E	E	-	-	-	-	-	-	-	-
		DH	G	G	G	G	G	G	G	G	G	G
		Distance	**385.2**	**385.2**	**342.9**	**342.9**	**301.2**	**301.2**	**266.1**	**266.1**	**240.45**	**240.45**
	800	BHC	A B C D F	A B C D F	9 A B C D E F	9 A B C D E F	9 38 A B C D E F	9 38 A B C D E F	9 30 38 A B C D F	9 34 38 A B C D F	9 21 34 38 A B D F	9 21 34 38 A B D F
		CHC	E	E	-	-	-	-	-	-	-	-
		DH	G	G	G	G	G	G	G	G	G	G
		Distance	385.2	385.2	342.9	342.9	301.2	301.2	282.3	282.3	267	267
	746.1	BHC	A B C D F	A B C D F	9 A B C D E F	9 A B C D E F	9 38 A C D E F	9 38 A C D E F	9 34 38 A C D F	9 34 38 A C D F	9 22 30 38 A D F	9 22 30 38 A D F
		CHC	E	E	-	-	-	-	-	-	-	-
		DH	G	G	G	G	G	G	G	G	G	G
		Distance	**385.2**	**385.2**	**342.9**	**342.9**	**321**	**321**	**301.2**	**301.2**	**285.9**	**285.9**
	700	BHC	A B C D F	A B C D F	9 A C D E F	9 A C D E F	9 30 A C D F	9 30 A C D F	9 22 30 A D	9 22 34 A D F	9 22 34 A D F	9 22 30 46 D F
		CHC	E	E	-	-	-	-	F	-	-	-
		DH	G	G	G	G	G	G	G	G	G	G
		Distance	**385.2**	**385.2**	**361.8**	**361.8**	**342**	**342**	**326.7**	**326.7**	**314.55**	**314.55**
	600	BHC	A C D E F	A C D E F	30 A C D F	34 A C D F	21 30 A D F	22 34 A D F	21 34 46 D F	21 34 46 D F	14 21 34 46 F	14 21 30 46 F
		CHC	-	-	-	-	-	-	-	-	-	-
		DH	G	G	G	G	G	G	G	G	G	G
		Distance	**404.1**	**404.1**	**384.3**	**384.3**	**369**	**369**	**356.85**	**356.85**	**353.85**	**353.85**
	500	BHC	C D F	C D F	39 C D	39 C D	22 39 D	22 39 D	14 21 39	14 21 39	14 22 39	14 21 39
		CHC	-	-	-	-	-	-	-	-	-	-
		DH	G	G	G	G	G	G	G	G	G	G
		Distance	**578.7**	**578.7**	**552.9**	**552.9**	**537.6**	**537.6**	**534.6**	**534.6**	**534.6**	**534.6**
	400	BHC	C	C	20	20	20	20	20	20	20	20
		CHC	-	-	-	-	-	-	-	-	-	-
		DH	G	G	G	G	G	G	G	G	G	G
		Distance	**935.25**	**935.25**	**895.5**	**895.5**	**895.5**	**895.5**	**895.5**	**895.5**	**895.5**	**895.5**

This appendix shows types and locations of healthcare facilities to be built from the varying infrastructure and operating budgets.

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APPENDIX C. TOTAL DISTANCE TRAVELED

Acceptance Level		Total Distance Traveled (km)			Healthcare Facility					
					Operated by Ethnicity A			Operated by Ethnicity B		
Ethnicity A	Ethnicity B	Ethnicity A	Ethnicity B	Total	BHC	CHC	DH	BHC	CHC	DH
1	0.1	308160	77040	385200	-	-	-	A B C D E F	-	G
1	0.2	308160	77040	385200	-	-	-	A B C D E F	-	G
1	0.3	308160	77040	385200	-	-	-	A B C D E F	-	G
1	0.4	308160	77040	385200	-	-	-	A B C D E F	-	G
1	0.5	308160	77040	385200	-	-	-	A B C D E F	-	G
1	0.6	308160	77040	385200	-	-	-	A B C D E F	-	G
1	0.7	308160	77040	385200	-	-	-	A B C D E F	-	G
1	0.8	308160	77040	385200	-	-	-	A B C D F	F	G
1	0.9	308160	77040	385200	-	-	-	A B C D	E F	G
1	1	308160	77040	385200	A B C D E F	-	G	-	-	-
0.9	0.1	374568	94347	468915	-	-	-	A B C D E	F	G
0.9	0.2	351300	114264	465564	C	-	G	A B D E F	-	-
0.9	0.3	351300	109611	460911	C	-	G	A B D E F	-	-
0.9	0.4	351300	104958	456258	C	-	G	A B D E F	-	-
0.9	0.5	351300	100305	451605	C	-	G	A B D E F	-	-
0.9	0.6	335844	110244	446088	C	F	G	A B D	E	-
0.9	0.7	326772	109395	436167	A B D E	F	-	C	-	G
0.9	0.8	326772	98610	425382	A B D E	F	-	C	-	G
0.9	0.9	315852	93642	409494	A B C D F	E	-	-	-	G
0.9	1	308160	77040	385200	A B C D E F	-	G	-	-	-
0.8	0.1	394440	118917	513357	C	-	G	A B D F	E	-
0.8	0.2	374568	132408	506976	A B D E	-	-	C	F	G
0.8	0.3	345384	152535	497919	A B D E F	-	-	C	-	G
0.8	0.4	345384	141750	487134	A B D E F	-	-	C	-	G
0.8	0.5	345384	130965	476349	A B D E F	-	-	C	-	G
0.8	0.6	345384	120180	465564	A B D E F	-	-	C	-	G
0.8	0.7	323544	126846	450390	A B C D E F	-	-	-	-	G
0.8	0.8	323544	110244	433788	A B C D E F	-	-	-	-	G
0.8	0.9	311184	103752	414936	A C D E F	-	G	B	-	-
0.8	1	308160	77040	385200	A B C D E F	-	G			
0.7	0.1	363996	174105	538101	A B D E	F	-	C	-	G
0.7	0.2	363996	163320	527316	A B D E F	-	-	C	-	G
0.7	0.3	363996	152535	516531	A B D E F	-	-	C	-	G
0.7	0.4	363996	141750	505746	A B D E F	-	-	C	-	G
0.7	0.5	331236	160050	491286	A B C D E	F	-	-	-	G
0.7	0.6	331236	143448	474684	A B C D E F	-	-	-	-	G
0.7	0.7	331236	126846	458082	A B C D E	F	-	-	-	G
0.7	0.8	331236	110244	441480	A B C D E F	-	-	-	-	G
0.7	0.9	312696	103752	416448	A C D E F	-	G	B	-	-
0.7	1	308160	77040	385200	A B C D E F	-	G	-	-	-
0.6	0.1	382608	174105	556713	A B D E	F	-	C	-	G
0.6	0.2	382632	163332	545964	A B D E F	-	-	C	-	G
0.6	0.3	338928	193254	532182	A B C D F	E	-	-	-	G
0.6	0.4	338928	176652	515580	A B C D E F	-	-	-	-	G
0.6	0.5	338928	160050	498978	A B C D	E F	-	-	-	G
0.6	0.6	338928	143448	482376	A B C D E F	-	-	-	-	G
0.6	0.7	338928	126846	465774	A B C D E F	-	-	-	-	G
0.6	0.8	314208	130464	444672	A C D	E F	-	B	-	G
0.6	0.9	314208	103752	417960	A C D E F	-	G	B	-	-
0.6	1	308160	77040	385200	A B C D E F	-	G	-	-	-

This appendix shows that total distance traveled by ethnicity group, type and location of healthcare facilities to be built, and the operators' ethnicity based on acceptance level.

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